PHILIPPINE WATER SUPPLIES

BY

GEORGE W. HEISE AND A. S. BEHRMAN

MANILA
BUREAU OF PRINTING
1918

152918

PHILIPPINE WATER SUPPLIES

BY

GEORGE W. HEISE AND A. S. BEHRMAN

MANILA
BUREAU OF PRINTING
1918

DEPARTMENT OF AGRICULTURE AND NATURAL RESOURCES
BUREAU OF SCIENCE
MANILA

Publication No. 11

Actual date of publication July 25, 1918

2

CONTENTS

ILLUSTRATIONS

[The following cuts were kindly loaned by the Bureau of Public Works: Plate II, fig. 2; Plate IV; Plate V; Plate VII, figs. 1 and 2; Plate VIII; Plate IX; Plate X; Plate XI; Plate XII, figs. 1 and 2; and Plate XIII, fig. 2; and photograph of Plate XV, fig. 2.]

PLATE XII

FIG. 1. Intake and spillway, Sariaya waterworks, Tayabas Province.
2. Bamboo waterwheel for hoisting irrigation water.

PLATE XIII

FIG. 1. Water wagon used in distributing drinking water to wealthy residents, Iloilo, Iloilo.
2. Fountain containing drinking places, faucets, wash places for laundry purposes, and bathing facilities back of concrete inclosure.

PLATE XIV

FIG. 1. Open stone aqueduct, part of the Spanish water supply system, Lucban, Tayabas Province.
2. Open ditches and gutters, part of the Spanish water supply system, Lucban, Tayabas Province.

PLATE XV

FIG. 1. A stream flowing through Bongabon, Nueva Ecija, a town with malarial index.
2. Sibul Springs bathhouse, Bulacan Province.

PLATE XVI

FIG. 1. Spring on seashore at Cebu, Cebu, completely covered at high tide.
2. Spring during rainy season.

PLATE XVII

Near view of the Salinas salt spring, Salinas.

PLATE XVIII

FIG. 1. Section of a boiler tube entirely closed with scale, taken from a neglected boiler in the provinces.
2. Section of the same tube, showing an iron cleaning rod broken off in an attempt to remove the scale.

PLATE XIX

FIG. 1. Apparatus used in field assay of water supplies.
2. The same, ready for transportation.

TEXT FIGURES

FIG. 1. The two sides of one card. The top of the obverse is the bottom of the reverse.
2. Decomposition of calcium hypochlorite in water.
3. Plan of apparatus for washing, sterilizing, and filling demijohns used in artesian water distribution.
4. Bureau of Science form No. 41 properly filled out.

PHILIPPINE WATER SUPPLIES

By G. W. HEISE and A. S. BEHRMAN

THE IMPROVEMENT OF PHILIPPINE WATER SUPPLIES

Perhaps in no single line of endeavor has better progress been made in the Philippines, especially during the last eight or ten years, than in the improvement and development of water supplies.

Previous to the American occupation little attention had been paid to the question of obtaining suitable water or of improving public supplies. Many comprehensive studies of existing sources, especially of mineral springs, had been published,[1]

[1] Among the principal articles before the American occupation dealing with Philippine water supplies, the following may be mentioned (compiled by J. Gonzales-Nuñez, chemist, Bureau of Science):

Abella y Casariego, Enrique, Aguas termosulfurosas en las emanaciones volcánicas subordinadas al Malinao, Islas Filipinas. M. Tello, Madrid (1885). Hidrografía en la región del Mayón o Volcan de Albay, Islas Filipinas. M. Tello, Madrid (1885). Hidrografía. La Isla de Biliran y sus azufrales, Islas Filipinas. M. Tello, Madrid (1885). Hidrografía y aguas termales. Descripción física, geológica y minera de la Isla de Panay, Islas Filipinas. Tipo-litografía Chofré y Ca., Manila (1890). Hydrografía y manantiales. Descripción física, geológica y minera de la Isla de Cebú, Filipinas. M. Tello, Madrid (1885). Manantiales termales en el Monte Maquiling y sus actuales emanaciones volcánicas, Filipinas. M. Tello, Madrid (1885).

Abella, Enrique, del Rosario, Anacleto, and de Vera, José, Estudio descriptivo de algunas manantiales minerales de Filipinas. Tipo-litografía Chofré y Ca., Manila (1893).

Becker, George F., Report on the geology of the Philippine Islands. *21st Ann. Rept., U. S. Geol. Surv.* (1901).

Centeno y Garcia, José, Lagunas del Volcan de Taal, Islas Filipinas. M. Tello, Madrid (1885). Memoria geológico-minera del Archipiélago Filipino. M. Tello, Madrid (1876). Noticia acerca de los manantiales termo-minerales de Bamban y de las Salinas del Monte Blanco en Nueva Vizcaya, Filipinas. Manila (1885).

Centeno, José, del Rosario, Anacleto, and de Vera, José, Memoria descriptiva de los manantiales minero-medicinales de la Isla de Luzon, Filipinas. M. Tello, Madrid (1890).

De la Cavada y Mendez-Vigo, A., Historia geográfica, geológica y estadística de las Islas Filipinas. Imprenta Ramirez, Manila (1876).

but no great progress had been made in making good water available to the bulk of the population. With comparatively few exceptions the eight million inhabitants of the Archipelago were entirely dependent on surface supplies, such as rivers and shallow wells, which were often dangerously polluted. There was probably not a single artesian well in the Islands. The single municipal supply system worthy of the name in the Philippines, that of Manila, was not installed until 1882. As the water had passed through a well-populated area, it was subject to frequent and dangerous contamination. There was no modern municipal sewage system in the Philippines, not even Manila being adequately provided.

Such conditions were typical of the Philippines and lasted for many years after the American occupation. The Director of the Bureau of Health has said:[2]

> With a few exceptions, the towns throughout the Islands are compelled to get their water from small rivers, springs, wells, irrigation canals, rain water, and any other source where water can be obtained; the rivers usually have towns on both banks for almost their entire length, and as the only system of sewage disposal is the ever-present pig or fly, the majority of the sewage is carried into the river by the first rain, if it has not already been thrown or deposited there by the people themselves.
>
> Springs are never protected, wells are never covered; rain water collected from nipa roofs is not clean and soon becomes filled with mosquito larvæ and other insect life.

Even where pure water was available, it was frequently carelessly handled and improperly stored, so that it became unfit to drink.

Superstition and customs peculiar to the Philippines have also played a large part toward rendering water supplies unsafe at various times in the past. Pilgrimages were frequently made by thousands of people to places of religious interest, though

Jagor. Viajes por Filipinas. Traducción del aleman por S. Vidal. Aribau Co., Madrid (1876), chapters 7, 8, 9, 13, 19, and 21.

Mallat, J., Les Philippines. Bertran (Editor), Paris (1846).

Mellado, Sanchez, Estudio de las aguas minerales de Carcar, Cebú, Islas Filipinas (1887). Manuscrito.

Montero y Vidal, José, El Archipiélago Filipino. M. Tello, Madrid (1886), página 57, aguas minerales.

P. P. Jesuitas, El Archipiélago Filipino. Imprenta del Gobierno, Washington (1900).

Von Drasche, Richard, Allgemeine Oro- and Hidrographie der Insel Luzon. Fragmente zu einer Geologie der Insel Luzon, Philippinen. Wien, Verlag von Karl Gerold's Sohn (1878). Datos geológicos de la Isla de Luzon, Filipinas. Madrid (1881).

[2] *Annual Rep. P. I. Bur. Health* (1906), 57.

these places often lacked proper sanitary facilities to provide for the needs even of their own inhabitants. Thus as many as 10,000 people in one day have visited the shrine at Antipolo, a small town until recently without adequate facilities for sewage disposal. The effect of so great an influx of people, many of them seeking relief from contagious diseases, can be readily imagined. To quote again from the records of the Bureau of Health:

> One of the greatest dangers connected with the pilgrimage [to Antipolo] is the fact that it is customary after visiting the Virgin to bathe in the river which flows by the town. The water for drinking and other domestic purposes is obtained from this river at a point below where the bathing takes place. In order to supply a better drinking water an artesian well has been dug. Unfortunately, the quality of the water is not of the very best, and on account of a slightly disagreeable taste it is almost completely eschewed by the people, who still continue to obtain their water supply from the river. Another source of great danger is the lack of proper facilities for the disposal of human excrements. The sanitary facilities of the town are not nearly sufficient to meet the demands of the great number of persons who go there.

Especially in the past, miraculous properties have been attributed to various water sources, notably springs, and many people have come to such places to obtain the supposed benefits to be derived from the waters. In some cases these waters came from highly contaminated sources; in others, the gathering of many people about an unprotected source gave rise to serious contamination.

Under such conditions it is not surprising that few Filipinos were free from intestinal parasites and that there were frequent and violent epidemics of water-borne diseases. Though there were, apparently, no serious outbreaks of typhoid fever, this disease was of common occurrence in the Philippines. Chamberlain [3] reported the typhoid death rate in Manila as 36.8 per 100,000. Terrible outbreaks of cholera occurred with alarming frequency. Though cholera vibrios have been seldom isolated from drinking water, it is beyond doubt that they can live for protracted periods in water [4] and that water is an important agent in spreading the disease. Dysentery, both amœbic and bacillary, was common. Though the work of Walker [5] and of Walker and Sellards [6] has shown that pathogenic amœbæ do not multiply in water and that the forms normally present

[3] Chamberlain, W. P., *Phil. Journ. Sci.*, *Sec. B* (1911), 6, 299.

[4] Schöbl, O., ibid., *Sec. B* (1914), 9, 479.

[5] Walker, E. L., ibid., *Sec. B* (1911), 6, 259.

[6] Walker, E. L., and Sellards, A. W., ibid., *Sec. B* (1913), 8, 253–331.

are not injurious to man, it is certain that cysts can exist almost indefinitely in water.

For a long time Manila had the highest infant-mortality rate of any city on record. There are not enough reliable sanitary statistics to enable comparisons to be drawn between Manila and the provinces, but there is no reason to believe that conditions were much better outside of Manila.

Discussing the infant mortality in Manila, Musgrave has said:[7]

> The next most important faulty custom consists in the dilution of milk compounds with unsafe water. In our investigation of the causes of death of three hundred babies, it is found that tap water, either with or without boiling, is used as a diluent in most instances. As a majority of the houses of these people are at considerable distances from the nearest faucet, the water is carted by water carriers and kept in earthenware jars or other vessels under the most unsanitary conditions; in many instances whatever safety might be secured by boiling the water is destroyed by the subsequent manipulations and care of the water and by the methods employed in making the dilutions of the milk mixtures.

Soon after its establishment the present civil Government instituted measures to improve conditions. Money was appropriated for the drilling of artesian wells, legislation was enacted to encourage the installation of municipal water systems, doctors and sanitary inspectors were sent to all parts of the Islands, waters were analyzed to determine their potability, studies of water-borne diseases were made, and a general educational campaign was conducted. The entire credit for the progress that has been made is not due to any one branch of the Government; the work of different bureaus was coördinate, interdependent, and equally important.

The construction of artesian wells and water-supply systems was greatly stimulated by Act 2264 of the Philippine Legislature. This Act, which was intended to minimize the cost of water installations to communities and individuals, provides—

> For drilling artesian wells, for the construction of water supply systems, and for the construction of cisterns where artesian wells cannot be sunk, whenever the provincial boards or municipalities interested shall adopt resolutions for the appropriation of funds covering the cost of one-third of the work, one hundred thousand pesos: *Provided*, That the Director of Public Works is hereby authorized to drill wells for private individuals upon the payment of one-third of the cost of the work, on condition that the public be allowed the use of the well: *Provided, also*, That from January first to July first, nineteen hundred and thirteen, in case of failure, when potable water is not found, the provincial board or the municipality

[7] Musgrave, W. E., ibid., *Sec. B* (1913), 8, 465.

shall not be obliged to pay part of the expense occasioned: *And provided further*, That the benefits of this Act shall apply to the special Provinces of Mindoro, Palawan, and Batanes.

This Act has been extended, so that its provisions are still in force (August 1917).

The first deep well to be constructed by the Insular Government was installed in 1906, in Mexico, Pampanga. Since that time the Bureau of Public Works alone has constructed over a thousand wells, while provincial governments and private individuals have constructed many more, of which no accurate record has been kept. The work of well-drilling performed by the Bureau of Public Works is summarized in Table I.

TABLE I.—*Wells drilled by Bureau of Public Works.*

Year ended June 30—	Deep wells driven.	Jet-rig wells driven.	Insular expenditure.
			Dollars.
1905	2	----------	6,500
1906	3	----------	6,000
1907	12	----------	14,000
1908	8	----------	21,000
1909	11	112	55,000
1910	15	159	98,500
1911	17	199	154,400
1912	41	104	154,500
1913	92	54	186,900
1913 (July 1-Dec. 31)	55	29	121,300
1914	103	----------	218,300
1915	139	----------	215,900
1916	122	----------	234,700

It has been estimated [8] that deep-well water is now available to over one-sixth of the entire population of the Islands.[9]

The effect on the public health of the pure water made available has been remarkable. Some towns, where artesian well water is exclusively used, have shown a 50 per cent reduction in mortality.[10]

The first artesian waters were looked upon with suspicion, and even now, in some sections, an artesian well furnishing

[8] Vickers, J. W., *Quart. Bull. P. I. Bur. Pub. Works* (1914), 2, No. 4, 24.

[9] It should be stated, however, that the number of people to whom water from deep wells is available is far greater than the number who actually use such water and no other for drinking purposes. Thus a sanitary survey of a certain town generally considered as being supplied with artesian water showed that all but 3,000 of a total population of 14,800 were dependent on water from surface wells or open water courses.

[10] *Annual Rep. P. I. Bur. Health* (1912), 73.

potable water will be abandoned in favor of an open surface well that is almost certainly polluted, but with which the inhabitants are familiar. In general, however, artesian water has grown very rapidly in favor.

The increasing employment of protected springs as sources of drinking water is another important contribution to the cause of the improvement of water supplies. This has been made possible, in a large measure, by the legislative Act quoted above. Many towns now obtain their drinking waters from springs through excellent distribution systems.

By the protection of watersheds and the construction of storage and distribution systems, several rivers have been made the basis of municipal water supplies. Manila installed a new water supply system in 1908, which has had a very beneficial effect on public health. Cebu and Zamboanga also have systems using river water. About 30 towns now have their own water works completed or under construction, and many others have well-developed projects for obtaining such installations.

The construction of adequate sewage disposal systems has made some progress, though perhaps not as much as has the development of water supplies. Manila, Baguio, and Cebu now have sewer systems.

Soon after the American occupation a large Government factory for the manufacture of ice and distilled water was installed. This plant has a daily production of almost 50,000 kilograms of ice and 20,000 liters of distilled water, in addition to which it offers the largest cold storage facilities in the Islands. Similar installations of smaller capacity have been installed elsewhere by the Federal and Insular authorities, and by private enterprise as well, so that ice and distilled water are now to be obtained in the principal cities throughout the Islands. However, the introduction of distilled water, though a great benefit, was not far-reaching in its effects because it was used only by the foreign-born or by the wealthy Filipino population.

The industry of bottling natural, distilled, and carbonated waters has flourished greatly. Owing to improper and careless methods of handling, bottled waters have not been an unmixed blessing. They, too, are used to a large extent only by the well-to-do, so that their effect has been restricted.

Health work went hand in hand with the construction program of the Bureau of Public Works. Quarantines were established in times of epidemic, and sanitary regulations were enforced. Wells were sterilized, and their surroundings were cleaned up. In every province work for sanitary improvement was organized.

In many towns, notably in Manila and Cebu, dangerous surface wells were filled as soon as better supplies were made available. Methods of sewage disposal on a small scale were devised, and a general educational campaign was conducted. As early as 1909 a complete medical and sanitary survey of a town [11] was undertaken coöperatively between the Bureau of Health, the University of the Philippines, and the Bureau of Science. Similar studies have been carried on from time to time.[12]

Recently sanitary commissions have been established by the Bureau of Health.[13] The work of these commissions, which is carried on with the coöperation of the Bureau of Science, has had great bearing on the problem of water supplies. A commission stays in a single town about two months, making a complete sanitary survey. In addition to the collection of vital statistics, the examination of inhabitants for parasites, the establishment of clinics and dispensaries, the formation of clubs and organizations that will stimulate interest in, and keep up the work of, sanitary improvement, considerable work is done that deals directly with water-supply problems. Maps are made, showing the location of all available supplies, all sources are examined biologically, and sanitary improvements are suggested. The work of the sanitary commissions though necessarily slow and confined to limited areas is thorough, and is producing permanent, beneficial results. The good that is being accomplished and the bearing of this work on the question of pure water supplies may be inferred from the following: A survey of six towns showed that only 2 per cent of the inhabitants were supplied with privies; in one town in which a sanitary commission had completed its labors 46 per cent of the houses were properly equipped, and privies were available to 58 per cent of the people.

The work of the Bureau of Science has kept pace with that previously described. As this Bureau is the central laboratory for all branches of the Insular Government, all the routine examinations of water, both chemical and biological, have been performed here. Each artesian well, or new source of municipal supply, has been examined by the Bureau of Science before being made available to the public. The Manila water supply

[11] Medical survey of the town of Taytay, *Phil. Journ. Sci., Sec. B* (1909), 4, 207–299.

[12] Sanitary survey of the San Jose estate and adjacent properties on Mindoro Island, Philippine Islands, with special reference to the epidemiology of malaria, ibid., *Sec. B* (1914), 9, 137–197.

[13] Long, J. D., *Pub. Health Rep.* (1916), 31, 2963.

has been tested daily for a period of years. In addition to the waters analyzed for different departments of the Government, many more have been examined at the request of private individuals. Instruction in the matters of sanitation has been given to officials of other bureaus. Much valuable information on water-supply problems has been collected and made available through the medium of press bulletins, pamphlets, and the various publications of the Bureau.[14] Studies have been made of the mineral and salt springs [15] of the Philippines. The geologists of the Bureau have given valuable assistance in deciding the location of deep wells and have given material aid in the installation of new water-supply systems.

In addition to matters of more or less routine nature, there has been carried on a large amount of investigation and research with direct bearing on the development and improvement of water supplies. The Manila water supply was the object of intensive study,[16] and plans for its improvement were developed. Of especially great importance have been the contributions to the study of water-borne diseases, such as typhoid, dysentery, and cholera.[17] Work has been also done on isolated problems, such as the purification of swimming pools,[18] the development of methods of sterilizing demijohns used for artesian water,[19] and the study and development of methods of analysis.[20]

The most important features of the work of the last three years has been a systematic field survey of Philippine water supplies, somewhat similar in character to the water surveys made under governmental auspices in the United States. For many practical purposes the field examination of water

[14] Cox, A. J., Heise, G. W., and Gana, V. Q., *Phil. Journ. Sci., Sec. A* (1914), 9, 243–412. Heise, G. W., ibid., *Sec. A* (1915), 10, 135–170. Edwards, R. T., ibid., *Sec. B* (1908), 3, 121–128.

[15] Cox, A. J., and Dar Juan, T., ibid., *Sec. A* (1915), 10, 375. Cox, Heise, and Gana, op. cit.

[16] Bliss, C. H., *Pub. P. I. Bur. Govt. Lab.* (1905), No. 20, 10. Walker, E. L., *Phil. Journ. Sci., Sec. B* (1911), 6, 259. Heise, G. W., ibid., *Sec. A* (1916), 11, 1.

[17] For the details of the work done on these diseases, see the papers cited in Contents and Index. The Philippine Journal of Science, Volume I (1906) to Volume X (1915). *Bur. Sci. Pub.* (1917), No. 8.

[18] Heise, G. W., and Aguilar, R. H., *Phil. Journ. Sci., Sec. A* (1916), 11, 105. Gabel, C. E., ibid., *Sec. B* (1916), 11, 63.

[19] Cf. Appendix, 212.

[20] Heise, G. W., and Aguilar, R. H., ibid., *Sec. A* (1916), 11, 37. Behrman, A. S., ibid., *Sec. A* (1917), 12, 291.

supplies has a number of advantages over the usual routine method of collecting samples at the source and conveying them to a central laboratory for analysis.

Cultures for bacteriological examination are made of the water as it emerges from the source. Chemical analysis is completed an hour or two after the sample is drawn. Consequently the data obtained in both cases are genuinely representative. More important even than this is the fact that the analyst himself takes the sample and, by means of a careful survey, becomes cognizant of all the factors that must be considered in passing final judgment upon the water under examination.

It is true that field determinations are not capable of the refined accuracy of those of the laboratory. Only "approximately quantitative" results are obtained, but for many purposes they are all that are necessary. The lines dividing good and bad waters for any purpose are necessarily broad, whether for drinking, for manufacturing, or for irrigation. Accordingly a chemical analysis will generally receive the same interpretation if the results are varied by 1, 2, 5, or sometimes even 10 per cent. Furthermore any loss in accuracy is more than compensated by the more representative nature of the data secured and by the wealth of other valuable information that would be impossible to obtain in the laboratory.

All of these considerations make field work particularly applicable to the Philippines. Water samples are often several weeks in transit before they reach the central laboratory in Manila. In addition, samples in many cases are not taken properly, and the analytical work, when performed, is therefore wasted.

The development of a number of projects for municipal water supplies, added to the general and rapidly increasing interest in pure water as related to the public health, made it extremely desirable that field investigations be performed. Accordingly, in 1914, the Bureau of Science took the necessary steps toward the beginning of a systematic water survey. The general plan adopted for the work was that outlined by Leighton,[21] of the United States Geological Survey. Practically no apparatus suitable for the work, however, was available; the distance from manufacturing centers made impossible the securing of such equipment within a reasonable length of time, and funds for obtaining it were not available. Accordingly the apparatus de-

[21] Leighton, M. O., *U. S. Geol. Surv., Water Supply Paper* (1905), No. 151.

scribed by Leighton was as nearly as possible duplicated by the Bureau of Science mechanics with such changes as the particular conditions here seemed to warrant. Reagents for the chemical work were also unavailable and were, consequently, made in the Bureau of Science laboratory.

The first field trip was made in September, 1914, to Mindoro, in connection with a number of projected municipal water systems. This was the beginning of a series of similar investigations, which have been continued, with several interruptions, up to the present time. Owing to the very limited personnel available, it has not been possible to carry on the work as extensively as conditions would warrant, but the results secured thus far have been of such great value that the continuance of the water survey on a larger scale is greatly to be desired.

Even if no allowances are made for the many delays due to transportation in the Philippines, the amount of field work that may be actually accomplished within a short time is surprisingly large. During the past year over 300 examinations have been made of waters at their sources, in 8 provinces, approximately one month being spent in each province.

Transportation is one of the most difficult features of field work in the Islands. There are three railroads. The largest of these operates on Luzon, north and south of Manila. The second connects the towns of Iloilo and Capiz, on Panay, and the third traverses the east coast of Cebu. A very limited portion of the Islands is thus made accessible. Between the islands, water transportation is naturally the only recourse. Numerous interisland steamers call at the important ports at more or less regular intervals. Between the small towns, steamers are rare, and small boats, with or without sails, are commonly used. In both cases too much dependence must be placed on weather conditions to make this method of transportation very satisfactory. Land transportation, where available, is usually much more expeditious. In several sections excellent roads permit the use of automobiles. In the remainder of the lowland districts recourse is had to a variety of wheeled vehicles. In the mountains pack horses and cargadores are used. The equipment for field work must, consequently, be of such a nature as to meet the demands put upon it in these varied modes of transportation.

Coöperation with the work of other branches of the Government has been a notable feature of the water survey. In numerous instances, where waterworks systems were being

proposed with little-known sources for their bases, the Bureau of Public Works has been able to obtain from our files the information required, without the expense or delay of a special investigation. In one case, where the choice lay between two sources, and the pipe was already on the ground, the water survey party, which happened to be in the vicinity, was able to show that one of the sources was very desirable, while the other was only river seepage. Again several artesian wells that had been reported unsuccessful and for which payment had been refused because of the alleged poor quality of the water supplied were shown to be satisfactory when analyses were made at the sources during water-survey investigations. In this way several thousand pesos were saved to the Insular Government, as well as assuring a safe source of water to the inhabitants.

The water survey has made another contribution to the public health by its coöperation with the health officials throughout the Islands. In one cholera-infected province, chemical, biological, and sanitary examinations were made of all commonly used or available drinking-water supplies. In this way the health officials were enabled to differentiate between the desirable waters and those that might be expected to spread the scourge. In another province, likewise cholera-afflicted, in which a number of deep-pumping artesian wells had been abandoned on suspicion of being infected, field investigations proved the purity of the artesian waters when the wells were properly kept up and showed the polluted condition of the surface wells that held a high place in the public opinion. A plan for the inspection and repair of the pumping wells was recommended to the district health officer, who promptly accepted it and made it a provincial health order at once. In still another province, where a barrio of 2,000 people was entirely dependent upon two polluted surface wells, it was possible, with the coöperation of the district health officer, to create sufficient interest to cause an artesian well to be drilled there within the next six months. "Miraculous" springs have been shown to be highly polluted sources.

Nor is its contribution to public health the only practical application of the water-survey investigations. The industries have been frequently assisted. The choice of waters for boiler or other industrial purposes has in a number of instances been decided from data on file, which had been secured in a previous field examination.

It is gratifying to note the appreciation of the work. In one province all the expenses of a month's field investigations were

borne by the provincial government, at its own suggestion. A large industrial corporation has requested a series of investigations, also at its expense. Many letters and resolutions of thanks and appreciation have been received from the various municipalities and provinces where the work of the water survey has been performed.

In short, then, the advantages of the water-survey investigations may be summarized as follows: A method is provided for making an intensive study of water supplies. Besides their value per se, these data are extremely useful in a variety of problems related to municipal-water supplies, to the public health, and to the industries. The expense of such a continuous and intensive study has been far less than would be attached to separate investigations to secure the same amount of information.

From the foregoing it will be seen that field methods of examination are applicable to the Philippines and that the results obtained thus far have proved their value. The water survey of the Philippines, however, has but fairly begun, and if it is to keep pace with the general development more attention should be given to this work in the future than has been given in the past.

The progress that has been made in recent years in sanitation and health conditions has been indeed gratifying, and the improvement noted, though doubtless due to many causes, must have been due in a great measure to the improvement in water supplies. There have been no epidemics of disease in recent years such as those that appeared in times past and decimated the population. Manila has been free from cases of cholera for periods of over a year at a time, and conditions in many provinces have also shown marked improvement. Best of all, there is a large and growing interest among the people themselves. Local political candidates include measures for the improvement of water supplies as planks in their platforms; provinces have requested and appropriated funds for surveys of water supplies; the Insular Government is loaning money for municipal installations; the field surveys of the Bureau of Science have made possible, in a number of provinces, the selection of proper bases for municipal systems; private individuals are drilling artesian wells; and in the larger towns the sale of bottled artesian and spring waters is steadily increasing.

WATER FOR DOMESTIC USE

The most important question pertaining to water supply problems is obviously the provision of an adequate supply of water suitable for drinking purposes. Even in temperate countries this task is becoming ever more difficult, due largely to an increasing population and to a more complex civilization. In the Philippines, as in many tropical countries, the desired result is rendered even more difficult of achievement by the entrance of a number of other factors. Surface supplies, which are hard to protect from pollution, are used in a large measure for domestic purposes. In countries with temperate climates epidemics of water-borne diseases usually decrease in violence with cold weather, owing to inhibition of bacterial growth in water and the freezing of possible avenues of contamination. In the Philippines the pollution of water and the course of an epidemic may proceed almost unchecked throughout the year. The heavy rains of common occurrence in the tropics wash accumulations of filth and decayed material into the surface water, so that the amount of water-borne diseases usually increases with the advent of the rainy season. Other factors that make it difficult to obtain pure water in the Philippines and to keep it uncontaminated are high temperature and humidity, and the resultant stimulation of decay and of bacterial growth; poverty and low standards of living; and outside of the larger cities, the lack of sanitary improvements. The problem is further complicated by the fact that many Philippine waters are so highly mineralized that they are not suitable for drinking purposes.

The best water for human consumption is that that is as free as possible from organic matter and that contains only in relatively small amounts the normal mineral ingredients of natural water. Such waters are free from objectionable taste or smell, and besides being low in bacterial content, must be free from all injurious organisms. The amounts of mineral matter may generally, however, be varied within wide limits without producing marked physiological effects. Well-aërated water, the mineral content of which is low, namely, below 300 parts per million, is generally considered to have the best taste. Water that contains more than about 1,000 parts per million of mineral matter in solution is liable to prove laxative or to

have an exceptional taste, although many waters, notably the waters from mineral springs, containing as high as 2,000 parts per million, are used constantly without deleterious effects.

A moderately hard water is probably to be preferred to a very soft one. Though this statement can be hardly regarded as definitely established, much evidence has been brought forward to show that the health of people living in localities where hard water is used is better than that of people using only soft water. For example, it has been claimed that people are stronger and better developed and that the nursing period of mothers lasts longer in places where hard water is used.

Waters that are unfit to drink may be divided into two classes, those that are naturally nonpotable and those that have been contaminated or polluted. In the first class are included waters that contain mineral poisons, those that contain excessive amounts of salts or organic matter, or those that are highly charged with gases that impart to the water a disagreeable taste or odor. Mineral poisons are very uncommon, and the other ingredients mentioned generally make water unpalatable, so that this class is of no great significance in its application to domestic supply problems. In the second class—by far the most important—are included waters that contain sewage or industrial waste or decaying animal and vegetable matter. It is the second class of waters with which problems of domestic water supply are chiefly concerned.

Under the heading Water for Domestic Use an attempt will be made to classify waters according to their sources, to discuss their importance as domestic supplies, and to give an account of some of the general factors influencing the problem of obtaining water suitable for domestic use in the Philippines.

RAIN WATER [22]

Because of its softness and freedom from dissolved matter, rain water is exceptionally good for domestic purposes. Especially in those parts of the Philippines where both ground and surface waters are poor in quality, this source should be an important one. The average annual rainfall is so great in most parts of the Islands that with proper storage systems entire communities may be readily provided with drinking water.

[22] In Manila, for example, the average annual rainfall is 194 centimeters (76.4 inches), while in Baguio it is almost 2.5 times as great. For the distribution of rainfall in the Archipelago, see Cox, A. J., *Phil. Journ. Sci., Sec. A* (1911), **6**, 287.

Unfortunately faulty methods of collection and storage have made rain water usually a doubtful and frequently a dangerous source of supply.

DISTILLED WATER

In the past, distilled water has been a much-used source of drinking water, especially among the foreign population. However, in recent years its use in Manila has been supplanted in a great measure by that of artesian well water.

Opinion is divided on the comparative values of boiled and distilled water for drinking purposes. If a mineral content is desirable in water, boiled water is undoubtedly better than distilled water. However, there is little evidence to show that the continued use of distilled water is harmful. Unfortunately water when boiled loses most of its air content and acquires a flat taste. The same holds true for distilled water. The decidedly objectionable taste that the distilled water sold in the principal Philippine cities has acquired at various times shows further the difficulty involved in keeping oil out of the distillate when water is being distilled on a large scale. As distilled water can be obtained on ship board and in the principal cities, a traveler who has accustomed himself to its peculiar taste frequently escapes the minor intestinal disturbances sometimes caused by abruptly changing from one kind of drinking water to another.

RIVERS AND WATER COURSES

Many of the Philippine water courses are low in dissolved mineral content and are chemically unobjectionable. Water from a well-safeguarded watershed is frequently very desirable for domestic use. In the Philippines, however, it is only in sparsely settled regions or in highland districts, such as Mountain Province, that this kind of water is obtainable in quantity from unobjectionable surroundings. In the lowlands the run-off is usually turbid. It may contain large amounts of decaying vegetable and animal matter. Above all, the density of population along the average water course and the lack of sanitary improvements in most Philippine communities make a high degree of pollution almost inevitable.

In many parts of the Philippines rivers and ditches constitute a grave menace to health. A large number of towns have water courses flowing through them. These are generally small, subject to tidal variations, and not very clean. Frequently they represent the only sewage system in the town, yet they often

furnish water for washing and other household purposes. Barber[23] has shown that they are very often breeding places for malaria mosquitoes (see Plate XIV, fig. 2).

SURFACE WELLS

Water from shallow wells usually has only a small mineral content and is unobjectionable from a chemical point of view. It is only with great difficulty that such water can be kept pure and uncontaminated. In Illinois 43 per cent of the wells examined recently were condemned. In Indiana over 50 per cent were found polluted, and a recommendation was made that every surface well in the state be abandoned. When such is the opinion expressed in the United States, the general undesirability of surface wells in the Philippines must be apparent.

The typical surface well in the Philippines is situated in a crowded barrio, very near to human habitations. It is generally open and uncovered and is frequently without casing or curbing, so that the first heavy rain may carry surface débris into it. The few outhouses provided for the disposal of sewage may be only a few feet distant. Animals are usually allowed to run loose in the vicinity. Washing clothes and bathing are commonly carried on at the wellside, though no adequate drainage for the dirty water is provided. Ordinarily no one vessel is used for drawing water, each comer bringing his own and lowering it into the well. It is only fair to state that in certain sections, principally among the wealthier residents, surface wells are lined and covered with concrete and are equipped with pumps. But this is exceptional and not the rule, and even in these cases lack of proper methods of sewage disposal and of other sanitary measures in the neighborhood usually nullify the minor precautions instituted at the well.

Practically every open surface well examined by the Bureau of Science has been shown to be dangerously polluted. Field bacteriological examination of surface-well waters largely used for drinking in seven towns in a certain province showed colony counts averaging 15,000 at the end of twenty-four hours and 25,000 at the end of forty-eight hours. Positive presumptive tests for the presence of the *B. coli* group were obtained in every instance.

In spite of the many sources of good water made available, especially in recent years, surface wells still furnish a large portion of the water used for household purposes in the Philippines,

[23] *Phil. Journ. Sci., Sec. B* (1915), **10**, 177–247.

even in many places where better water is at hand. It cannot be too strongly emphasized that these sources constitute a grave menace to public health. The difficulty of safeguarding surface supplies from contamination is shown by the fact that during cholera epidemics excessive rainfall has increased the number of cholera cases among the people dependent on surface wells.

It must be admitted, however, that, especially in isolated districts, great dependence will continue to be placed on surface wells for some time to come. In these cases an effort should be made to enforce sanitary measures that will minimize, if not eliminate, the dangers from drinking surface water. All wells should be cased, curbed, covered with water-tight (preferably cement) tops, and provided with pumps. Adequate drainage should be provided to prevent the accumulation of waste water or surface run-off, washing at the well side should be prohibited, and animals should be kept at a distance. The immediate surroundings should be kept clean. Above all, the well should be located as far as possible from a dwelling, stable, or outhouse, as pollution may occur by infiltration through the soil. These steps will improve the quality of the well water, but will not insure purity. A surface-well water is always questionable and should be used only until a safer supply is made available.

LAKES [24]

In the Philippines lakes are, on the whole, undesirable as a source of drinking water. They are generally small, frequently turbid, and usually subject to contamination. However, they are so few and widely scattered that they have little significance as sources of water for drinking purposes and merit no detailed consideration here.

SPRINGS

Typical spring waters are usually more highly mineralized than surface water; hence they are more likely to contain chemically objectionable ingredients. They usually contain considerable amounts of free carbon dioxide. In consequence they dissolve large quantities of calcium and magnesium carbonate, especially in limestone regions, and are, therefore, "hard" waters. Though the dissolved minerals will usually be much smaller in amount in shallow springs than in those that have passed through more and deeper strata, the quantity even in the latter

[24] For a description of the principal Philippine lakes, cf. Pratt, W. E., *Phil. Journ. Sci., Sec. A* (1916), 11, 223–237.

case is usually not prohibitive. There is a great variety and abundance of springs in the Philippines, many of them comparing favorably with some of the best-known foreign mineral and medicinal springs. A more detailed discussion of the chemical composition of typical Philippine spring waters will be found further on.

Spring waters in the Philippines have been usually found bacteriologically pure at the point of emergence. On the whole they are excellent sources for household use, and it is, therefore, not surprising that many municipal water-supply systems now derive their supply from springs. It should be noted, however, that springs are frequently subject to fluctuations, both in quality and in quantity, and should be carefully studied before they are used indiscriminately. Thus a spring of flow amply to supply a town's needs during the rainy season may be entirely inadequate after a long-continued period of drought. Furthermore it frequently happens, especially in limestone formations, that surface seepage may find its way into the underground stream that supplies the spring, thus making the water unfit to drink. Such contamination is usually very hard to detect, as it may only occur at infrequent intervals. In this connection a distinction must be drawn between real springs and those that, in spite of their appearance, are nothing but seepage water from the surface or that are water from a neighboring stream that has worn an underground channel for itself. In the town of Majayjay (Laguna), for example, bacteriological examination of a group of much-used springs on a river bank showed a high degree of bacterial pollution. A close examination of the surroundings revealed the fact that the supposed springs were merely the outlets for the water of a neighboring river, the exact points where the river water entered the soil being discovered.

Even when a spring is uncontaminated and chemically unobjectionable, certain precautions are necessary to ensure a safe water supply. If possible, the ground above the spring, from which contamination might proceed, should be reserved from settlement. The surroundings of the spring should be kept scrupulously clean and guarded from trespass in much the same way as was described for shallow wells. The outlets should be kept clean and clear of weeds or accumulations of débris. Whenever possible, it should be walled in, so that it cannot become contaminated. When the water is allowed to collect in a basin or reservoir, this should be of stone or concrete and should be

covered. An outlet pipe should be provided, from which the water can be obtained without danger of contaminating the entire supply. Adequate drainage for waste water should be, of course, ensured.

BORED, DRIVEN, OR PUNCHED WELLS [25]

In some parts of the Islands, where water is found at depths not greater than 15 to 17 meters, and where there are no hard strata to be pierced, iron tubes, generally 2 to 4 inches in diameter, have been sunk by hand or by horsepower. Such wells are frequently capable of furnishing excellent water, especially if they penetrate clayey materials and are located far enough from habitations so that the danger from surface seepage is minimized.

DEEP WELLS [26]

In the drilling of wells in the Philippines standard machinery was used for penetrating to great depths; for depths of less than 85 to 90 meters, and in the absence of hard or difficult strata, small, specially designed, hand-power "jet rigs" were employed.

Many of the wells drilled in the Philippines are of the flowing type, and most of them are "artesian," in the generally accepted sense of the word; that is to say, the water in them rises above the level at which it is encountered. Deep-well waters in the Philippines have been found as a rule to be more highly mineralized than spring waters. At times the degree of mineralization is sufficient to render the water unserviceable for drinking purposes. The principal impurities noted in this connection are abnormally large amounts of common salt and iron. Analyses of typical deep waters will be found in Table XVI. Biologically deep wells have been found very satisfactory, so that, on the whole, they are the most desirable sources of drinking water available for general use in the Philippines at the present time.

Flowing wells are to be preferred to the other types of deep wells, not only because they require no pump, but because they are of better biological quality. The water from flowing artesian wells in the Philippines is sterile. This was shown by Barber,[27] who found that "the waters from the flowing wells show a remarkably high degree of bacterial purity and may be

[25] For a discussion of different types of wells and their relative advantages, see Fuller, M. L., *U. S. Geol. Surv.*, *Water Supply Paper* (1910), No. 255.

[26] For an account of well-drilling operations in the Philippines, see Vickers, J. W., *Quart. Bull. P. I. Bur. Pub. Works* (1914), 2, No. 4, 24.

[27] Barber, M. A., *Phil. Journ. Sci., Sec. B* (1913), 8, 458.

regarded as safe from pollution by pathogenic bacteria," and has been amply corroborated by our field survey of waters. The conclusion is a natural one. Owing to the time the water has been underground and the filtration to which it has been probably subjected, the initial purity of artésian water as it leaves the deep strata may be safely assumed. In a flowing well the pressure is outward, so that the ingress of surface waters, which might introduce foreign and contaminating material, is prevented.

One of the few precautions or sanitary measures that should be observed with regard to a flowing well is the provision of adequate drainage away from the source. The accumulation of water near a well is unsightly and unsanitary, and it frequently provides breeding places for mosquitoes.

An improvement much to be desired in connection with the use of flowing artesian wells deals with the conservation of underground water supplies. Almost every well of this type in the Philippines is allowed to flow continuously. In this way not only is the greater part of the water wasted, but the supply for the future is diminished as well. The water-bearing stratum is drained, and the flow of the well gradually diminishes or even ceases entirely. When the flow is much greater than is needed by the community, the outlet should be decreased in size. To place self-closing faucets on artesian wells, so the flow would be stopped when water is not needed, would result not only in the conservation of the ground water, but also in the general sanitary improvement of the surroundings.

> When flowing wells are not in use the interests of the community require that they be shut off. It is as illogical to permit flowing wells to run continuously and to expect them to maintain their flow as it would be to open the fire hydrants in a city and then expect the pressure to be maintained.[28]

Artesian wells are a great asset to a community, and when once they have failed through abuse or neglect, they can be seldom regenerated.

Deep pumping wells, though not quite as desirable as flowing wells, usually give very excellent water if the pump is in good condition and if the casing is intact. The results of field bacteriological examinations indicate that the average pumping well will yield bacteriologically pure or impure water depending on

[28] Deussen, A., and Dole, R. B., *U. S. Geol. Surv., Water Supply Paper* (1916); No. 375, 168.

whether or not the pump is protected against, or exposed to, the entrance of contaminating influences. A well that has to be primed occasionally, often with water from sources that are at least questionable, must almost inevitably become contaminated at some time. Sanitary conditions, in general, at the well-side constitute, of course, a factor not to be neglected, but other things being equal, the condition of the pump may be taken as a fair index of the bacteriological quality of the water. This has been shown in a number of instances by examination of a well water, both when the pump was in poor operating condition and again after repairs had been made and the well had been subjected to a thorough pumping test. The results of the field bacteriological examinations of the water of a number of typical pumping artesian wells will be found in Table XVI.

There are two general, preëminent evils, both of them readily obviated, that tend to lessen the value of deep pumping wells in the Philippines. One is the unsanitary condition of the surroundings of many wells. The necessity for keeping the surroundings of water sources clean has been already mentioned. Though surface seepage does not readily find entrance to a properly constructed well, contamination is always possible through imperfections at the junctions of pipes, especially when the water supply is obtained from some distance below ground level. The greater evil, however, is the general condition of the well equipment in the provinces. In a field investigation covering a large number of towns dependent on deep pumping wells, the proportion of pumps entirely inoperative or in poor condition varied from 25 to 67 per cent. It has been already pointed out that a pump in poor condition is an invitation to pollution. Exposing an otherwise pure water to contamination, or entirely depriving a community of good water, is a real evil and one that is worthy of every effort for its correction.

It has been estimated that in the United States alone substitution of pure for impure water supplies would save some 26,000 lives annually. Johnson,[29] in a discussion of water purification, states that pure water in urban (United States) communities alone would prevent 45,000 typhoid cases and 3,000 deaths yearly. No such estimate has been made for the Philippine Islands, but the generally unsatisfactory conditions of water supplies and the difficulty of keeping them pure, due to climatic factors, location, and local customs, make it evident that the preventable

[29] Johnson, George A., *Eng. Contr.* (1917), 47, 46–47.

waste of life and resources is enormous. That pure water is one of the first requisites for good health in the tropics is demonstrated by the fact that, in the Philippines, the improvement of water supplies by the drilling of artesian wells or by the utilization of springs or carefully protected water courses has been invariably followed by a marked decrease in the death rate. In some places, formerly dependent on surface supplies, the introduction and general use of artesian water has been accompanied by a decrease in death rate as high as 50 per cent.

Conditions are still far from satisfactory in many parts of the Archipelago. In too many cases dependence for drinking water is put on the nearest available source, quality often being a consideration of secondary importance. Large areas are still unsupplied with water other than that from dangerous surface wells or unclean water courses.

Iloilo, a city of 50,000 inhabitants, is still unsupplied with a municipal water supply or with an adequate sewage system. Many towns now unsupplied have easily accessible sources of pure water, which might be utilized at small expense.

It has been estimated [30] that from 80 to 96 per cent of the Filipinos are afflicted with intestinal parasites. The Director of the Bureau of Health in a recent statement to the press [31] has said that reports from six towns show infection with intestinal parasites ranging from 94.9 to 100 per cent. There can be little question that impure water is a great factor in bringing about such a state of affairs.

The lack of proper methods for the disposal of human excreta [32] is a great obstacle in the way of securing suitable drink-

[30] Garrison, P. E., Leynes, R., and Llamas, R., *Phil. Journ. Sci., Sec. B* (1909), 4, 261.

[31] Manila Daily Bulletin, July, 1917.

[32] Voy a hablaros de dos costumbres de los moros, que tienen íntima relación con la sanitación: La de defecar en el agua y lavarse después, no importando que el sitio sea el del manantial en que se provean del agua de beber. Cuando muere un moro los "panditas," que son los sacerdotes, se hacen cargo del cadáver, le bañan bien y le exprimen el abdomen mientras haya líquido que le salga por la boca y por el ano, y después le envuelven en una tela blanca; terminada esta operación, la familia del muerto, con los "panditas" y hasta los curiosos, se ponen a comer al rededor del cadáver. Esta costumbre ha sido causa de la propagación rápida de varias enfermedades, especialmente de cólera. [Fajardo, Jacobo, El problema sanitario en Mindanao y Sulu, Actas, Memorias y Comunicaciones de la Tercera Asamblea Regional de Médicos y Farmacéuticos de Filipinas (1917), 297.]

ing water and is one of the most serious menaces to public health in the Philippines. In six towns recently examined, only 28 houses with flush closets and 251 with other types of privies were found; in other words, only one home in fifty was so equipped. In poorer and more isolated communities this state of affairs is even worse.

However, great progress has been made, and it is to be hoped that this progress will continue. With the advance of education and the improvement in standards of living, a corresponding improvement in water supplies may be confidently predicted.

STORAGE AND DISTRIBUTION OF WATER

Storage of water in large quantities has been practiced since the earliest times of which we have authentic record. The prehistoric reservoirs in New Mexico and Arizona, the remains of tanks and cisterns in India, and the installations of the Egyptians, Carthaginians, Greeks, and Romans show what stress was laid by the ancients both on the quantity and on the quality of water. An idea of the vastness of some of the ancient projects may be derived from the fact that a reservoir in Ceylon, built in 460 after Christ and recently restored, holds a body of water 6 meters (20 feet) deep, having a surface area of 1,800 hectares (7 square miles).

Storage is necessary, because of the fluctuations in quantity of the average source of supply and because of the variation in the average community's demand for water, depending on the season or on the time of day. Especially in countries like the Philippines, where the rainfall occurs, for the most part, during three or four months of the year, water must be stored during the wet periods to ensure an abundant supply during the dry season. Storage, in general, would be desirable, even if not necessary, because of the improvement in quality generally effected in the water. This factor will be discussed more at length under Purification.

In the Philippines storage of water on a large scale is practiced in only three cities, namely, Manila, Cebu, and Zamboanga. In each case two types of reservoir are represented: an impounding reservoir, in which water is stored by means of a dam thrown across a river; and a service reservoir, in which the water is kept prior to its entrance into the distribution system. These installations, together with some of the more important smaller systems, will be discussed more at length later on.

In properly constructed municipal systems the impounding reservoir serves to store a raw water, the service reservoir to hold the purified supply. When water from a river is used, it is essential that the reservoir should receive water only from a watershed well protected from contamination. Therefore, when, as is usually the case, a dam is constructed to catch the water in a valley, the site of the reservoir is of great importance.

The bottom of the catchment area should be cleared of weeds, rubbish, and other material that will affect the water deleteriously. The reservoir should not be less than from 8 to 10 meters deep, in order to inhibit the growth of algæ and other water plants that do not grow at greater depths and that may have a harmful influence on the water. For the same reason the sides should be as nearly perpendicular as possible, so that no growths or sediment may adhere to them. The immediate surroundings of a reservoir also require attention. The margins should be kept free from weeds, accumulations of leaves, and other débris; the adjacent strips of ground should be planted in such a way that the soil will not be washed away and that the water will be protected from dust; and suitable channels should be provided to prevent contamination from surface drainage. In order to take the greatest advantage of the beneficial effects of storage, the inlet should be placed as far as possible from the outlet.

The same precautions hold for service reservoirs as for impounding reservoirs. As the former are usually smaller than the latter, they can be constructed with more care and with greater attention to detail. The sides can be made steeper, and special methods can be employed to ensure a uniform period of storage or to prevent stagnation.

When only a single reservoir is provided, or when water has not undergone a sufficiently long storage period in the impounding reservoir, it is often advantageous to have a reservoir divided into compartments. With this arrangement water will not find its way directly from inlet to oulet. Sedimentation is facilitated, and the major portion of the precipitate collects in the first compartments and can be removed without interrupting the work of other compartments.

Because of the scarcity of good water and the paucity of municipal installations in many parts of the Philippine Archipelago, storage on a small scale, usually of rain water, has been much practiced. In Iloilo, a city of approximately 50,000 people, rain water continues to be one of the chief sources of water for drinking purposes. Every well-constructed house has a galvanized iron roof from which the rain water flows into one or more tanks. The town of Capiz has developed a project for catching rain water from the roofs of the principal public buildings. A reënforced concrete tank with a capacity of a million liters has been recently erected. Even in places where other waters are available, many people depend in a large measure on rain water.

There is no valid objection to the use of properly collected rain water, stored in well-constructed, frequently cleaned cisterns. All of the rain should not be collected; the first portion should be rejected by means of any of a number of automatic mechanical devices constructed for that purpose. A cistern should be made of metal, slate, or concrete rather than of wood. In the first case it must be remembered that rain water has an appreciable solvent action on metals, particularly lead and zinc, and that both of these metals are deleterious to health. The use of copper or nickel-plated iron has been recommended.[33] Cisterns should be closed, to prevent the entrance of contaminating substances, but should be so constructed that they can be cleaned out periodically.

Unfortunately the advantages of rain water as a source of water supply are frequently nullified by improper methods of collecting and storage. The rain that falls on a roof, especially one of nipa or thatch, should not be collected until all accumulations of dust or dirt have been thoroughly washed away. All too frequently water becomes foul and stagnant, and the cistern becomes a breeding place for mosquitoes. The common practice of collecting rain water in loosely covered ollas is strongly to be condemned for similar reasons.

A settlement or community usually develops at or near a source of good drinking water. As the community enlarges and the chances of contamination increase, water must be carried increasingly greater distances. It is not surprising, therefore, that aqueducts and elaborate distribution systems have been used since very early times.

There is great variation in the amount of water required for each inhabitant in different cities. The supply of ancient Rome is estimated as having furnished 1,260 liters (332 gallons) per capita per day. The weighted average per capita consumption of water for representative cities in the United States is 375 liters (100 gallons) per day; English practice is based on an estimated daily consumption of 115 liters (30 gallons); figures for Germany vary from 85 liters (22 gallons) to 125 liters (33 gallons). Representative data are not available for the Philippines, not only because of the relative scarcity of municipal installations, but also because very frequently such installations are not used freely and exclusively by all the community to which water is supplied. Manila uses about 225 liters (60 gallons) per capita per day.

[33] Rideal, S. and E. K., Water Supplies. D. Appleton and Company, New York (1915), 28.

Municipal water installations that include elaborate systems of house distribution are restricted in the Philippines to comparatively few towns. Manila, Baguio, Cebu, and San Pablo (Laguna) are examples of towns well provided in this respect. The more important installations will be discussed later. In some installations water is piped directly to the various houses; in others it is piped only to conveniently located points, whence it may be carried in small containers to the individual homes. In all cases, however, public hydrants are made a part of the system, so that the people who cannot afford house connections can secure water free of charge. Such installations have invariably had a great beneficial effect on the health of a community.

An interesting type of municipal distribution system is found in the so-called canal towns, notably those on the slopes of Mount Banajao, in Laguna and Tayabas Provinces. Lilio, Nagcarlan, Majayjay, Lucban, Tayabas, and Sariaya are typical towns of this group. By a system installed in the days of the Spanish occupation, the water from mountain springs is brought through ditches and open stone canals to a series of laterals, which distribute the water to all parts of the town (Plate XIV, figs. 1 and 2). These laterals are nothing but open gutters, and not only provide readily accessible sources of water for laundry and other purposes, but frequently furnish a means for disposing of sewage and other refuse. Though these systems may have furnished a better supply of water than that available previous to their installation, they were, on the whole, extremely unsanitary and decidedly undesirable and dangerous sources of water supply. In addition, these systems have been shown [34] to be excellent breeding places for *Anopheles febrifer*, the mosquito causing malaria. In view of these facts it is a source of gratification to know that the majority of the towns in question have either installed new systems (for instance, Sariaya) or else (for example, Majayjay and Nagcarlan) have well-developed projects for obtaining a better supply.

Various other methods of distribution are employed. An ingenious and economical method sometimes used for piping water to a center of population from a source not very distant is by means of a bamboo pipe line. Much of the distilled and artesian water sold in Manila is sent to the consumer by autotrucks in large tanks. The use of these tanks is carefully supervised either by the Federal or the Insular authorities, and satisfactory

[34] Barber, M. A., et al., *Phil. Journ. Sci., Sec. B* (1915), 10, 223.

152918——3

results are obtained. A large quantity of water is also distributed in bottles and demijohns. The difficulty encountered in sterilizing containers, especially in some of the smaller companies supplying water, has made this method of distribution unsatisfactory in certain instances. In Iloilo, spring water brought from Guimaras in paraos and water from surface wells in the outlying districts are sold from cans or from small tank carts. On the whole, this method is very unsatisfactory, because the surface wells are dangerous sources, and even the initially good water from Guimaras is frequently contaminated before it reaches the consumer.

In all cases where house connections are not provided there is necessarily an intermediate carrying of the water from the source to the place of consumption. Unfortunately the containers used for this delivery are not always kept clean, so that a pure water frequently becomes contaminated in transit. The commonest vessel used is a 5-gallon gasoline or oil can. Two of these, slung at opposite ends of a pole, or *pinga* (Plate VI, fig. 1), constitute a load for a water carrier. The charge for water thus carried depends on the distance; it varies from about 2 to 5 centavos for the cans when a source is near and from 10 to 20 centavos when a source is distant.

In the provincial districts the common method of carrying water (Plate VI, fig. 2), especially among the poorer classes, is in a section of bamboo, the joint partitions of which have been removed. These bamboo tubes are easily made and cost practically nothing, while empty oil cans have a considerable market value, which increases with the distance from the large towns.

For the sake of completeness brief descriptions of some of the principal Philippine municipal installations are appended.

MANILA [35]

The water for the municipal supply for Manila comes from an uninhabited, guarded watershed of about 1,550 square kilometers (600 square miles). A dam across Mariquina River, above Montalban, about 25 kilometers from Manila, gives a storage basin with an estimated capacity of over 4,700,000 cubic meters (1,250,000,000 gallons), though this amount is not actually available, owing to leakage through fissures and cracks in the

[35] For a more complete discussion, see Heise, G. W., *Phil. Journ. Sci.*, *Sec. A* (1916), 11, 1–13.

limestone walls of the river gorge. From Montalban the water is piped to the high ground just outside of Manila to a service reservoir, the capacity of which is about 206,000 cubic meters (54,500,000 gallons); thence it passes through a large service pipe to Manila, where it enters the main distribution system. In normal times the water supply is adequate for the city's needs; in periods of extended drought, however, it has been occasionally found necessary to resort to the old (Spanish) installation at Santolan, which takes water directly from Mariquina River, in a well-populated area.

The water is not treated in any way until it reaches the exit of the service reservoir, where a small chlorination plant for adding chloride of lime has been installed. The water reaches the main distribution system about forty-five minutes after it has been treated.

The new supply system is a tremendous improvement over the old installation. Even before chlorination was introduced, the Bureau of Health[36] pointed out that there were 300 per cent more deaths from intestinal diseases in the years just preceding the installation of the new supply than in the years immediately following and showed[37] further that when the inadequacy of the Montalban supply made it necessary to resort to the old Santolan system a marked increase in the death rate occurred. However, the city supply is still far from being entirely satisfactory. Though a considerable improvement is effected by storage in the reservoirs, adequate sedimentation and bacterial purification do not occur. Consequently the water as it leaves the reservoir is still somewhat turbid, especially in rainy weather, and has a rather high bacterial content. Chlorination has failed to reduce the bacterial content to the extent usually obtained in general practice, owing partly to the turbidity and organic content of the water, partly to irregularities in dosage, and partly to the accumulation of foreign matter in the distribution system. Filter beds, as well as measures to ensure adequate sedimentation, seem to be necessary to ensure good results.

CEBU

The city of Cebu is supplied by the Osmeña waterworks, completed in 1912. A reënforced concrete dam and spillway in a narrow gorge at Buhisan, about 6 kilometers from the city,

[36] *Ann. Rep. P. I. Bur. Health* (1912), 5.
[37] Ibid., 47.

impound between 1,000,000 and 1,500,000 cubic meters of water—at least one hundred days' supply. In addition, a concrete distribution tank holds some 15,000 cubic meters more. This large storage capacity gives ample time for sedimentation and purification. A distribution system with direct house connections and a number of public hydrants is provided. With the exception of one occasion, when a large amount of mud accumulated behind the dam, the tap water has been clear and colorless and of a very satisfactory bacteriological quality.

ZAMBOANGA

The municipal system of Zamboanga derives its water from a river about 10 kilometers from the poblacion. The basin formed by the dam is about 50 meters above sea level. From here the water is led through a 30-inch reënforced concrete pipe to a reservoir about 4 kilometers distant. This reservoir has a capacity of 2,270 cubic meters (600,000 gallons), approximately three and two-fifths days' supply for the city. Cast iron pipes conduct the water the remaining 6 kilometers to the town. The intake is cleaned once every five days; the reservoir, once every ten.

In the city there are 270 house connections and 53 public hydrants. In this way approximately 5,000 people are supplied, or about 20 per cent of the population of the entire municipality.

BAGUIO

Baguio, Mountain Province, has a well-developed water-supply system. It derives its water from a series of mountain springs of excellent chemical quality, flowing directly into comparatively small storage basins, whence the water is pumped to the distribution system. Though the water is unobjectionable in quality during most parts of the year, it is planned to purify it further with an ultra-violet light-sterilizing apparatus.

There are many other municipal distribution systems, as the appended tabular data indicate, but most of these present no unusual features that need be discussed here. Most of them employ springs or rivers and operate by gravity, but several use pumping wells with satisfactory results. In addition to the towns listed, all subprovincial capitals in Mountain Province, except Kabugao, have installed small gravity systems.

TABLE II.—*Water works completed or under construction in the Philippines.* [a]

Town.	People served.	Source of water.	Type of system.	Cost.
				Pesos.
Antipolo		Well	Pump	
Balayan				4,350
Baguio		Springs	Pump	
Bani, Pangasinan	2,000	River	Gravity	18,000
Boac, Marinduque	4,000	Wells		7,500
Calapan		Springs	Pump	
Capiz		Rain water		13,000
Cebu	38,000	River	Gravity	547,000
Duero	2,000	Spring		8,500
Jolo		Creek	Ram	70,000
Loay			Gravity	
Moalbual	1,500	Spring	do	15,000
Naga	5,000	do	do	7,000
Parang	600	River	Ram	9,000
Pasig		Wells	Pump	
Sariaya	4,200	Spring	Gravity	36,000
Sibonga	5,000(?)	do	do	30,000
Subic	1,800	do		8,500
Taal	8,000	do	Pump	64,000
Vigan	10,000	do		116,000
Zamboanga	5,000	River	Gravity	305,000

[a] From data furnished by the Bureau of Public Works.

PURIFICATION OF WATERS

A water from a source subject to contamination by substances dangerous to health must be treated before it can be used for drinking purposes. Many methods of purification have been devised, the one to be used in any instance depending upon the quantity of water to be treated and the special conditions or factors affecting the problem in hand. Artificial purification of water on a large scale has been tried in only one case in the Philippines, namely, in Manila, so that any discussion of methods must be necessarily based largely on experience elsewhere.[38]

The discussion under Purification of Waters will deal solely with purification of waters for drinking purposes; the treatment of water for other purposes will be discussed under industrial supplies. Methods of purification have been practiced since very early times. Medical literature written in Sanskrit, perhaps four thousand years ago, contains the following statement:[39]

> It is good to keep water in copper vessels, to expose it to sunlight, and to filter it through charcoal.

The use of alum for the coagulation of muddy waters has been familiar to the Chinese for thousands of years. Hippocrates, about 400 before Christ, advised boiling and filtering impure water that was intended for drinking purposes. The old Roman aqueducts were even provided with the "castella," a series of chambers that gave excellent opportunity for sedimentation to take place.

Purification of water may have reference to the removal of turbidity or color (or odor and taste), to the elimination of injurious chemicals or those (for example, iron) causing a disagreeable taste, or to the destruction of pathogenic organisms.

The principal methods of purification that will be considered here are self-purification, effected by storage, illumination, or aëration; physical methods, such as distillation, boiling, filtra-

[38] Cf. Don, J., and Chisholm, J., Modern Methods of Water Purification. Edward Arnold, London (1911). Johnson, G. A., Purification of public water supplies, *U. S. Geol. Surv.*, *Water Supply Paper* (1913), No. 315. Mead and Turneaure, Public Water Supplies. 2d ed. (1913).

[39] Johnson, op. cit., 24.

tion, and the use of ultra-violet light; and chemical methods, such as treatment with coagulants or the addition of copper sulphate, ozone, chlorine, or lime.

PURIFICATION OF WATER ON A LARGE SCALE

It is well known that water is generally improved greatly by ordinary natural processes. Sunlight and aëration are so bactericidal that a surprising degree of purification is frequently effected in water, especially when it becomes well aërated, by flowing over rocks or other obstructions. Unfortunately this form of self-purification cannot be relied upon to any extent in the Philippines, as the density of population along a water course usually causes a greater pollution than would be obviated by natural agencies.

Storage may also be of decided value in purification under ordinary conditions both biologically and chemically. When water is impounded in a reservoir, its flow ceases or, at least, decreases so greatly that silt and suspended matter begin to settle. Flad [40] observed that after twenty-four hours of storage only 5.5 per cent of the salt originally present in Mississippi River water remained in suspension. After ninety-six hours this decreased to 3.0 per cent. In addition to clarification, a decrease in color and organic matter, and usually in hardness, is produced. The precipitate entangles bacteria and carries them down with it, so that a considerable degree of purification is effected by simple sedimentation. There are, however, other ways in which storage has beneficial influence on the biological quality of a water. Sewage bacteria and pathogenic organisms, in general, rapidly die in water, and there is strong evidence to show that ordinary forms disappear as well or, at any rate, that they do not multiply persistently. In the ordinary form of reservoir, open to the sunlight and air, a marked degree of purification takes place.

Houston,[41] in his reports to the Metropolitan Water Board of London, found that after three weeks' storage the total number of bacteria per cubic centimeter in Thames River water fell from 450 to 53; in Lee River water, from 620 to 106; in New River water from 220 to 48. The decrease in numbers of pathogenic bacteria was especially rapid. In the reservoir at Lawrence, Massachusetts, where water is stored about two weeks, the bacteria removal amounts to over 93 per cent. At Wash-

[40] Rideal, op. cit. (1915), 61.
[41] Rideal, op. cit. (1915), 65.

ington, D. C., the bacterial removal is about the same as in the Boonton reservoir, where the Jersey City supply is impounded; a five to six days' storage in the former and a two hundred days' storage capacity in the latter effect an average bacterial purification of 99 per cent.

Even in the dark the influence of nitrifying bacteria in the presence of air may effect purification. Water remaining in the old Manila "deposito," a covered reservoir having a capacity of about 60,000 cubic meters (16,000,000 gallons), becomes practically sterile in the course of a few weeks, in spite of a high initial bacterial content. Preliminary experiments [42] indicate that in the new Manila reservoir, which has about three days' storage capacity, the various factors—sedimentation, aëration, and light—produce a bacterial reduction of about 90 per cent.

It frequently happens that certain forms of plant life make their appearance, especially in reservoirs of faulty construction. These may cause odors, interfere with processes of purification, and when dead contaminate the water with decaying material, causing "stagnation" of the water. The remedy or preventive measure to be applied depends on the case in hand. Reservoirs must be frequently cleaned to remove accumulations of sediment and decaying matter. Sometimes aëration is resorted to; sometimes, especially when the trouble is due to algæ and other growths, the addition of very small amounts of copper sulphate (0.15 to 1.0 part per million) gives the desired results. Trouble due to stagnation is, perhaps, more likely to appear in tropical than in temperate regions. However, the experience in Manila and Cebu indicates that, with proper construction and supervision, reservoirs in the Philippines need give no unusual amount of difficulty. The Manila reservoir requires frequent cleaning, because of the large amount of suspended matter in the water, but no pronounced stagnation has occurred. This, however, is hardly a criterion, because of the small storage capacity of the reservoir in question. The Cebu reservoir, which impounds at least one hundred days' supply, has caused trouble only on one occasion, and then the removal of the accumulated mud in the reservoir brought about a return to satisfactory conditions.

So far, filtration of water on a large scale has not been attempted in the Philippines. Sand filters have, from time to time, been suggested for the Manila city supply, but since experiments in the Bureau of Science had shown that amœbæ pass

[42] Heise, G. W., *Phil. Journ. Sci., Sec. A* (1916), 11, 5.

through the average filter, their introduction was not considered advisable. However, this objection to their use no longer holds, as Walker[43] has shown that the amœbæ ordinarily growing in water will not cause dysentery in man.

There are two kinds of sand filters, the rapid and the slow. Slow sand filters are adaptable to clear, raw water. They have a daily capacity of about 23,000 cubic meters per hectare of surface area (2,500,000 gallons per acre); and their cost, including settling basins and filtered water reservoir, is about 16,000 pesos per million liters' capacity (30,000 pesos per million gallons). Aside from the initial cost of installation, the actual cost of water filtration for Manila should be about 36 centavos per capita per annum.

Rapid sand filtration is particularly applicable to water highly colored or heavily charged with suspended matter. In the latter case a coagulant such as alum must be used to aid the separation of the substances in suspension. The filtration rate is approximately forty times that of slow sand filters, and the cost of installation, including the necessary filter building, filters, and coagulating and filtered water basins, is about 6,500 pesos per million liters' daily capacity (12,000 dollars, United States currency, per million gallons). The cost in Manila for rapid sand filtration should be about 30 centavos per capita per annum.

A new open filter is not as efficient as one that has been in operation for some time. The activity of an open filter bed is chiefly centered in the first few centimeters and is due to the gelatinous film that is formed from the removed suspended and colloidal matter. In this film reside myriads of organisms, chiefly algæ and bacteria, which act on, and decompose, part of the organic matter of the water being filtered. In rapid mechanical filtration, where coagulants are employed, an inorganic film is formed as the gelatinous mass of aluminium or iron hydroxide subsides.

Both types of filters generally remove 98 to 99 per cent of the bacterial content of the water.

In recent years the sterilization of public water supplies by means of the ultra-violet rays from a quartz-mercury vapor lamp has been repeatedly accomplished with very good results. This method is simple in practice and has the advantage of adding no foreign or deleterious substances to the water so treated.

[43] Walker, *Phil. Journ. Sci., Sec. B* (1911), **6**, 259. Walker and Sellards, ibid., *Sec. B* (1913), **8**, 253.

Water can be sterilized almost instantaneously regardless of its bacterial content. The method is applicable only to very clear waters, so that sterilization of a slightly turbid water, such as that of the Manila supply, is out of the question. For small installations using clear water, ultra-violet sterilization should prove very satisfactory. The proposed utilization of a small sterilizer of this type in the Baguio water system should give good results.

Sterilization by the addition of chemicals is now extensively employed, usually in conjunction with coagulants and filtration. A number of materials have been proposed, but actual practice is restricted almost exclusively to alum (coagulant), ozone, copper sulphate, lime, and chlorine.

The use of alum has been already mentioned in connection with filtration. Very turbid water must be clarified before it is susceptible to treatment by practically any method of purification. Alums are almost universally used for clarifying purposes, since they react with the carbonates normally present in water, giving rise to flocculent precipitates that inclose, and thus eliminate, not only the silt and other suspended matter, but also a large fraction of the bacterial content. There is absolutely no evidence to show that the introduction into the water supply of alums in properly regulated amounts has the slightest deleterious effect on the human system.

The ozone treatment is relatively hard to administer, is applicable only to filtered water, and though excellent results are claimed for it, is not, at the present time, very widely used.

That copper sulphate is valuable as an algicide has been already pointed out. It has been also used to reduce the bacterial content of water. It is probably not injurious to health, but its use is open to several objections. It causes turbidity with certain classes of water, and its bactericidal effect is not all that might be desired. Stokes [44] reports that a concentration of one part of copper sulphate in 100,000 parts of water failed to destroy fermentative bacteria. Experiments in the Bureau of Science have shown that the addition of one part per 150,000 was necessary to kill cholera vibrios in Mariquina River water.

Purification of water by the use of lime alone has received much attention in recent years. The method is being employed at present in a number of municipal installations in the United States and in Europe. It is essentially a water-softening proc-

[44] *Am. Med.* (1905), 10, 1075.

ess and is especially applicable to hard waters. A slight excess of lime above the requirements for softening is the basis of the "excess-lime" method of Houston,[45] in which the excess is subsequently removed by carbon dioxide or by the sulphates of iron or aluminium. The materials precipitated in the treatment settle rapidly and are readily filtered off.

Not only is a chemical purification obtained, but a great reduction in the number of bacteria as well. The disappearance of intestinal bacteria is particularly marked. Hoover and Scott[46] ascribe the disappearance of the colon and typhoid bacilli to the removal of carbon dioxide from the water by the lime treatment and state that "bacteria belonging to the colon or typhoid group seem to require carbon dioxide for their development." The principal reduction in the number of bacteria is due to the coagulation of the precipitated calcium carbonate and magnesium hydrate.

The advantages of the lime treatment are thus summarized by Hoover and Scott:

1. The water is softened.
2. Intestinal and pathogenic bacteria are killed and thereby the water is rendered safe bacterially.
3. The water is clarified.
4. Color is removed.
5. Lime-softened water is not corrosive to iron pipe, thus no trouble is experienced from the accumulations of "red-water" in dead ends of the distribution system.
6. The sterilizing action of lime persists indefinitely.
7. Nothing is added to the water that was not there originally, as the lime combines with the CO_2 present in the water to form calcium carbonate ($CaCO_3$) which is insoluble and is removed.

Because of its cheapness and general efficiency, chlorine, in the form of hypochlorites or liquid chlorine, is now one of the most generally used chemicals for the purification of public water supplies or the emergency sterilization of sewage. The value of calcium hypochlorite as a disinfectant was first pointed out by Koch,[47] while its application on a large scale to the disinfection of a municipal supply was first proposed by Traube.[48] It was not until 1908, however, when hypochlorites were used

[45] *Eighth Rep. Metropolitan Water Board,* London (1912), through Rideal, Water Supply (1915), 175.

[46] Hoover, C. P., and Scott, R. D., The use of lime in water purification, *Eng. News* (1914), 72, 587.

[47] Koch, R., *Mitt. a. d. kaiserl. Gesundheitsamte* (1881), 1, 234–282.

[48] Traube, M., *Zeitschr. f. Hyg.* (1894), 16, 149–150.

successfully in water purification in the stock yards at Chicago,[49] that the hypochlorite sterilization of municipal water supplies was adopted to any great extent.

The amount of hypochlorite necessary for efficient sterilization cannot be definitely stated, as it varies greatly with the quality and temperature of the water, on the methods of administration of disinfectant and distribution of water, and possibly also on other factors.

Water from the same source often requires different amounts of hypochlorite for treatment, depending on slight variations in the quality of the water. It may even happen that a small quantity of hypochlorite is as effective as a much larger one.[50] In general practice the most efficient quantity is usually in the neighborhood of one part of available chlorine per million of water (1 milligram per liter), though the actual amount to be used for any installation should be carefully determined by chemical and bacteriological control.

Though no definite rule can be stated, it may be said that such a quantity of hypochlorite should be added that ten minutes later the addition of potassium iodide-starch indicator will give a slight blue coloration. This rule admits of exceptions.

A decided advantage of chlorination is the absence of poisonous features. The amounts of free chlorine that reach the consumer in a well-administered distribution system are so slight that they are of no significance.

It often happens that chlorinated waters acquire a perceptibly unpleasant taste or odor. This has been frequently noted in Manila. It can be usually avoided by careful regulation of dosage, by filtration through iron, charcoal, or sand, by storage, or by the addition of suitable chemicals, such as sodium sulphite or sodium thiosulphate. A humorous feature in connection with chlorination arises from the popular antipathy to the use of treated water. In a number of instances [51] vigorous complaints of the "chlorine" taste and odor of a water were made some weeks before a proposed chlorination treatment had been put into operation.

In case of epidemics or of sudden contamination of waters it sometimes becomes necessary to use more than ordinary quan-

[49] Johnson, G. A., *U. S. Geol. Surv., Water Supply Paper* (1913), No. 315, 65.

[50] Stokes, W. R., and Hachtel, F. W., *Journ. Am. Pub. Health Assoc.* (1916), 6, 1224–1236.

[51] Kellogg, *Rep. U. S. Pub. Health* (1914), 29, 687.

tities of hypochlorites, with the result that the water becomes unpalatable. In this event the excess chlorine can be readily destroyed by the addition of "antichlors," such as the sulphite or thiosulphate of sodium.

Chloride of lime is still the most commonly used chlorination agent, though at the present time both sodium hypochlorite and liquid chlorine are being used extensively. The advantages of chloride of lime are its cheapness, its compact form and the consequent ease with which it can be handled, transported, and stored, and the fact that its administration is comparatively simple and easy, so that the expense for equipment, labor, and supervision is not great.

Simple and efficient methods have been also devised for the chloride of lime sterilization of small municipal supply systems and for use in emergencies. With the development of municipal water-supply systems, such methods should be applicable in the Philippines, not only for emergency, but for ordinary sterilization.

The use of liquid chlorine for water purification, first introduced on a commercial scale by Darnall [52] in 1910, is rapidly growing in favor. In the Philippines, where there is no chlorine gas manufactured, this method is not applicable at present, but in countries where chlorine is a cheap by-product, its use is often to be recommended. Its advantages are the fact that no salts are added to the water and that, according to report, the taste and odor of the treated water are often less than when chloride of lime is used. The disadvantages are a higher initial cost of installation, a somewhat higher cost for chemicals, the need of a higher grade of labor in administration, expert supervision, and the danger of corrosion in the administration apparatus. It appears, however, that most of these objections can be overcome or, at least, that the advantages under certain conditions outweigh the disadvantages, for, according to Birsall,[53] the substitution of liquid chlorine for chloride of lime in the purification of the municipal supply of Minneapolis has proved successful, and the city "would never again return to the use of hypochlorite if it were possible to avoid it."

Sodium hypochlorite is readily prepared by the electrolysis of a solution of common salt or by the interaction of common soda and bleaching powder. The salt is unstable; hence it is used only in solution, generally as an alkaline liquid containing about

[52] *Journ. Am. Pub. Health Assoc.* (1911).
[53] Birsall, L. D., *Eng. News-Record* (1917), 78, 539.

10 per cent of available chlorine. Its disadvantages are a high initial cost of installation and the need for expert supervision. Its advantages are ease of administration and the fact that no objectionable salts are added to water. The claim has been made [54] that sodium hypochlorite has a greater sterilizing effect than chloride of lime and that, in the end, its use is more economical. The electrolytic process appears particularly suitable for small units, such as supplies for small towns or for troops in the field. The Ornstein process [55] is used in the European war for sterilizing water supplied to English soldiers. Efficiency tests by the Bureau of Science on a small electrolyzer have shown that the electrolytic process could be readily adapted to meet Philippine conditions.

The preceding discussion has dealt almost entirely with the removal of organisms deleterious to health. Also chemical constituents of a water may be objectionable, either because of their nature, or because of the large amounts present. As has been stated, filtration may remove part of the dissolved organic matter. The commonest inorganic materials that require special treatment for their removal are iron and calcium and magnesium compounds. Calcium and magnesium compounds, though making the water "hard," are not usually objectionable in themselves, even in comparatively large amounts, when the water is to be used for drinking purposes only.

Iron is objectionable when present even in very small quantities. It can be usually removed by aëration. Iron is usually present in water as ferrous bicarbonate and is acted upon by the oxygen of the air to form ferric hydroxide, which may be removed by filtration.

The removal of calcium and magnesium compounds, a process known technically as water softening, is discussed at length under industrial supplies.

PURIFICATION IN THE HOUSEHOLD

When water must be purified in individual homes, boiling is, perhaps, the simplest safeguard in so far as contamination due to living organisms is concerned. It has not been practiced in the Philippines to any considerable extent by the mass of the population, except during times of great stress, such as cholera epidemics. Even when so practiced, the good effects have been often vitiated by subsequent handling of the water with dirty

[54] Rideal, op. cit., 187.
[55] Anon, *Electrician* (1917), 78, 750.

hands and in dirty vessels. It will be a difficult task to bring about the general adoption of this precaution; the cost of fuel, the inadequacy of cooking facilities in the average home, the peculiar taste of boiled water and superstitions regarding its harmful character, and lack of comprehension of the purpose of boiling, all militate against its use.

Though distillation is not a common method of purification of water for home use, it has been so extensively practiced in the Philippines that it is worthy of brief mention here. Both the Federal and the Insular Governments maintain their own installations. Distilled water can be obtained in most of the larger cities, either from Government or from privately owned distilling plants. In Manila the price of distilled water has been 1 centavo (0.005 dollar) per liter, and until recently the foreign and wealthy native population depended entirely on this supply for drinking purposes. All dissolved or suspended matter is removed from water by distillation. The cost of equipment and fuel is an important factor in determining the feasibility of distillation as a method of purification.

Another mode of purification of water for home use is filtration. Many types of filters have been devised for home use. These usually employ sand, charcoal, or porous earthenware and are either attached directly to a faucet or tap or are used separately. Though many forms are really capable of purifying water if properly cared for, the usual types are too small adequately to purify the water passed through them, and they generally do not receive sufficient care to keep them in good condition.

Various other types of sterilization appliances are made for use in the home, such as heating devices, electrical ozone generators, and the like. These, however, are not of sufficiently general application to Philippine conditions to justify detailed discussion here.

PURIFICATION IN THE FIELD

Considerable attention has been devoted to water supplies for troops, and a number of methods of field purification are now employed. Several of these are merely slight modifications of the processes already described in connection with purification of water on a large scale and so need no extended discussion. A few, however, are possessed of special features that warrant further mention.

In the United States Army the Darnall filter and Lister bag are used. The first device provides for purification by means

of coagulation and subsequent filtration through flannelette bags. Most of the suspended matter and a large part of the bacteria are thus removed. Salts of iron or aluminium are used for coagulation in the presence of some neutralizing agent such as lime or soda ash.

The Lister bag is a bag of heavy canvas, holding about 150 liters (40 gallons) and provided with five spigots. Calcium hypochlorite is added to the water in the bag, effecting chemical sterilization.

The Darnall filter clarifies water, but does not insure sterilization. The Lister bag sterilizes, but does not clarify. A combination of the two processes should be effective.

Numerous other types of filters and "filter candles" are employed to a limited extent, but these, as a rule, have not been found very satisfactory, except for the use of small units. The effort usually involved in their operation on a large scale is much greater than that required for other processes just as efficacious and no more expensive. Most of these filters are modifications of the Pasteur filter, consisting of porous earthenware through which the water is forced under pressure. The Berkefeld army filter is a good example of this type. A hollow porous tube is inclosed in an outer metallic case. The raw water is forced through the porous material and emerges clarified and sterile. Another filter of this type consists of an inverted funnel about the size of a watch, to which a rubber tube and mouthpiece are attached. Water can be then sucked through the tube. Another form consists of a cup or small pail into which water slowly filters. Such devices are satisfactory only if they are frequently cleaned and sterilized, the latter being readily accomplished by baking.

Boiling is, of course, a reliable means of sterilization, and is valuable for the use of small units. Often a weak tea is made, to increase the palatibility of a water. For the purification of large supplies, however, boiling is ordinarily uneconomical and impracticable.

Sterilization by ozone or by ultra-violet rays is usually impracticable in the field, though it may be employed where electric power is available.[56]

On the whole, chemical sterilization appears to be the most generally satisfactory method for troops in the field. It is cheap and efficient. Chlorine is the sterilizing agent commonly

[56] Anon, *Can. Engr.* (1916), 30, 189–90, through *Chem. Abst.* (1916), 10, 1063.

employed either in the gaseous condition or as calcium or sodium hypochlorite. The United States Army has devised an efficient apparatus for sterilization with chlorine gas for camp use,[57] and sterilization of this kind seems destined to become more popular.

Nelson[58] describes an apparatus for preparing chlorine in the field by the oxidation of hydrochloric acid with potassium chlorate. While excellent results are claimed for the apparatus and its use, there can be no great advantage in making chlorine by this process.

At present chloride of lime is more generally used than chlorine gas, and a number of methods have been employed for its use in the field. In permanent or semipermanent encampments its applications do not differ materially from those in municipal purification plants, which have been already discussed. For troops in temporary camps or on the march, the time factor is important. The usual procedure in this case is to add a comparatively large excess of available chlorine, providing rapid sterilization, and then to neutralize the excess with some reducing agent or "antichlor." The antichlor most commonly used is sodium thiosulphate (hypo), though the advantage of greater palatability is claimed for hydrogen peroxide.[59]

The chloride of lime may be used alone or in conjunction with an alkaline permanganate solution.[60] Sodium hypochlorite may be employed, either as such,[61] or as in alkaline solution (antiformin). Rhein[62] suggests the use of hypochlorous acid derived from the action of hydrochloric acid on concentrated antiformin.

An interesting development of field-water purification has been the sterilization of a supply for the individual soldier. In the movements of small parties of troops, particularly of cavalry, when the camp is not within reach, the question of a small supply of potable water for immediate use often becomes a serious one. In addition to those already described, a number of methods of purification have been proposed, the majority taking the form of powders or pellets of various kinds.

[57] Darnall, C. R., Water purification for troops in war, *Bull. War Dept., Office Surg. Gen.* (1913), No. 2, 116.

[58] *Brit. Med. Journ.* (1915).

[59] Doyon and Toda, *Compt. rend. Soc. biol.* (1916), **79**, 232–233.

[60] Pénan, H., *Journ. Pharm. chim.* (1916), **13**, 377–85, through *Chem. Abst.* (1916), **10**, 2487.

[61] Doyon and Toda, loc. cit.

[62] Rhein, M., A new method for the sterilization of drinking water in the field, *Zeitschr. f. Hyg.* (1914), **78**, 562–70.

In 1901 Parkes and Rideal[63] introduced the use of sodium acid sulphate ($NaHSO_4$) for travelers and in campaigns, in the strength of 15 grains per pint (2 grams per liter). Such salt was successfully used in the Boer and English war. It is still used extensively in pellet form by the British Army.[64] The pellets are made up with oil of lemon and saccharin, to increase the palatability, and are employed in such quantities as to provide a concentration of 0.07 per cent of free sulphuric acid in the water to be sterilized. A half hour is allowed for bactericidal action. A great disadvantage of this method is the corrosive action of acid solutions on the metals, such as those used in canteens.

Many other substances have been proposed, most of which will give satisfactory results if they are properly used. Among them may be mentioned the use of from 4 to 6 drops of tincture of iodine, followed by a pinch of sodium thiosulphate;[65] the addition first of potassium permanganate and then of sugar; and the use of pellets and powders, such as mixtures of salt and bleaching powder.[66]

The question has been occasionally raised whether or not purified water might not be injurious to health, owing to the presence of dead bacteria. With reference to this point, Vosmaer[67] has made the following calculation: Assuming a water had the enormous bacterial content of 100,000 per cubic centimeter, or 375,000,000 per gallon (3.78 liters), the space occupied by the bacteria per gallon of water would be only 0.000024 cubic inch. Since bacteria are 90 per cent water, he concludes that the amount of foreign material in water, due to the presence of bacteria, is insignificant.

[63] Rideal, op. cit. (1915), 171.

[64] Thorndike, Saville, Military sanitation in the present war, *Am. Journ. Pub. Health* (1917), **7**, 547.

[65] *Schweiz. Apoth. Zeitg.* (1914), **52**, 717, through *Chem. Abst.* (1915), **9**, 495.

[66] Langer, H., *Chem. Tech. Rep.* (1914), **38**, 146.

[67] Vosmaer, A., *Met. & Chem. Eng.* (1913), **11**, 705.

WATER FOR INDUSTRIAL PURPOSES

So many industries require a water suitable in quality as well as abundant in supply, that it is not surprising that the problem of water supplies for industrial purposes should be considered important, but rather that its importance should be so little emphasized. The use of improper supplies is still causing an annual loss of millions of pesos, even in countries in which industries are well developed and intelligently supervised. For example, on one section of a certain railroad in the United States the use of poor boiler water resulted in a cost, for repairing and cleaning of locomotive boilers alone, of 10 centavos per kilometer (16 centavos per mile) of distance run, while the total mileage of the engines was probably reduced one-half.[68] As an illustration of the saving that can be effected by the substitution of a better water for an improper supply, it may be mentioned that, according to estimation, the inhabitants of Glasgow, Scotland, by using the soft Loch Katrine water instead of the previous supply, save 300,000 pesos annually on the item of soap alone.[69]

In view of the undeveloped state of Philippine industries in general, it is not surprising that the question of the fitness of waters for industrial purposes should have been little considered in the past. It is worthy of mention, however, that proper attention to this problem would have effected a tremendous saving in many fields of commercial enterprise. Even the most obvious factor, that of quantity, has frequently been overlooked, to the great detriment of the industry in question. Thus a certain mining company, after investing heavily in expensive machinery and equipment, found that the water available for power purposes was adequate only for a few months in the year.

In another instance an agricultural enterprise, representing a large investment of foreign capital, almost failed through the neglect of the promoters to take into account the fact that the annual rainfall, though more than sufficient for their needs, was unequally distributed throughout the year. The extent to which water is used in ordinary manufacture is frequently overlooked.

[68] Leighton, M. O., *U. S. Geol. Surv.*, Water Supply Paper (1903), No. 79, 14.

[69] Rideal, op. cit. (1915), 141.

Thus it has been estimated [70] that from 40 to 1,600 liters of water are used in the manufacture of a single kilogram of paper.

Failure to take quality of water into account has also proved costly in the Philippines. An annual loss of many thousands of pesos would have been avoided in one city alone by the substitution, for improper boiler waters, of supplies available at comparatively small cost. A chemical analysis and its proper interpretation would have obviated a number of costly failures in cement and reënforced concrete construction. The use of a very undesirable water in one of the centers of the Philippine tanning industry has greatly impeded [71] the development of the local manufacture of leather.

A factor of importance in the problem of industrial water supplies in the Philippines arises from the frequent variation in quality of certain waters. Many of the rivers that flow into the sea are affected by the tides for many kilometers inland, so that, at certain times of the day, they are decidedly brackish. For this reason a certain river water used for irrigation can be pumped on to the fields only at certain times of the day. A study of the variation in the composition of one river water enabled this laboratory to decide between two proposed types of under-water construction, with the result that one, which undoubtedly would have rapidly deteriorated, was rejected.

Up to the present time, the principal industrial use of water in the Philippines has been for the production of steam, but the industrial development of the last few years indicates that the question of a suitable water for a particular purpose will assume an ever-increasing importance.

Though many excellent boiler waters are available in the Philippines, the problem of securing a good water is often an exceedingly difficult one. In Manila and in Cebu the surface waters supplied by the municipal systems are fairly satisfactory; in Iloilo, however, the waters available until recently were uniformly bad. The development of new supplies in the last-mentioned place makes it probable that conditions soon will be greatly improved. On the coastal plain of Occidental Negros, the largest and most important sugar-producing district in the Islands, excellent boiler waters are obtained from the surface streams originating in the range of volcanic mountains that forms the rocky backbone of the province. Several boilers

[70] Palmer, C., *U. S. Geol. Surv., Water Supply Paper* (1909), No. 233, 185.

[71] Cf. Gana, V. Q., The leather industry of the Philippine Islands, *Phil. Journ. Sci., Sec. A* (1915), 10, 349–373.

using these waters were found to be almost free from incrustations and showed no effects of corrosion after continuous use during an entire milling season (three to six months), without more cleaning than an occasional blowing-off of the water in the boiler. On the other hand, cases might be cited of a power company that has been spending approximately 500 pesos a month in replacing incrusted and corroded boiler parts and of a large manufacturing concern that was forced to distill its water to be used for boiler feed purposes because of the entire unsuitability of the raw water.

Both types of the instances mentioned are exceptional. It would be a fair statement, however, to say that comparatively few of the natural waters of the Philippines are suitable for boiler purposes without previous treatment. In practice, the nearest source is used. As intelligent treatment is the exception rather than the rule, and as, in the majority of cases, there is no treatment at all, the usual boiler troubles are encountered. Because of their frequency and importance, these will be discussed separately.

The phenomenon of foaming is the formation of bubbles on the surface of the water in a boiler, thereby hindering the free escape of the steam. This tendency is noted in waters rich in sewage or other organic matter and is increased by the presence of mud or other suspended matter. Probably the commonest cause, however, is the high concentration of dissolved alkali salts, either those naturally occurring in the water or those resulting from chemical treatment of the feed water.

As foaming is largely a question of surface tension, it may be temporarily relieved by surface blowing. The only remedy for foaming due to high salt concentration is blowing off and diluting with fresh feed water. This is not only uneconomical in regard to fuel, but due to the greater amount of water employed, may increase the amount of incrustations.

Intimately connected with foaming is the condition technically known as priming. This is the passage of water with the steam. The tendency of a boiler to prime is affected by the design of the boiler and by the steam space; it generally increases as the steam space diminishes.

Corrosion of a boiler may be due to chemical or galvanic action. Chemical corrosion may be due to two causes—solution or oxidation. Stabler has developed the following formula for determining the corrosive quality of a water from its chemical composition, expressed in terms of parts per million:

The "coefficient of corrosion," $c = H + 0.1116\ Al + 0.0361\ Fe + 0.0828\ Mg - 0.0336\ CO_3 - 0.0165\ HCO_3$.

If c is positive, the water will certainly corrode a boiler. If $c + 0.0503$ Ca is negative, the mineral constituents in the water will not cause corrosion. If c is negative, but $c + 0.0503$ Ca is positive, corrosion may or may not occur, the probability of corrosive action varying directly with the value of the expression $c + 0.0503$ Ca.[72]

A feed water's solvent action is due principally to the presence of acid. Mine waters with free mineral acids—usually sulphuric—and waters containing hydrogen sulphide or free carbon dioxide are typical instances of acid feed waters. Marked corrosive tendencies have been generally ascribed to waters containing magnesium chloride, on the assumption that, at working boiler temperatures, hydrochloric acid is split off hydrolytically. So much evidence to the contrary has been brought forward, however, that the exact rôle played by magnesium chloride is still in dispute.[73] A water may become acid through the decomposition of grease that works into the boiler. This may result in serious corrosion. The presence of acid-free volatile oil is actually beneficial in a boiler, assisting in scale prevention and in the reduction of rust.

Very soft waters and those with a chlorine content of over 200 parts per million will be usually found to have corrosive properties.

In general, alkaline waters are not corrosive, though it has been shown that, in the case of sodium and potassium carbonates, there is a critical concentration below which solution of these salts have a corrosive, instead of protective, tendency.[74] The common remedy for acid waters is the addition of a slight excess of alkali over the amount required to combine with the mineral and organic acids present. Lime is inexpensive and usually efficient. Its use often results in the formation of a thin protective scale; which prevents further corrosion. Barium hydroxide has been also recommended for the correction of the acidity of mine waters,[75] but its relatively high cost would probably prohibit its extensive use commercially.

A small amount of oxidation of the boiler material normally

[72] Stabler, H., *U. S. Geol. Surv.*, *Water Supply Paper* (1911), No. 274, 170.

[73] Ost, H., *Chem. Zeitg.* (1902), 26, 819, 845; also Bradbury, *Chem. News* (1913), 108, 307.

[74] Friend, J. Newton, The Corrosion of Iron and Steel. Longmans, Green & Co., New York (1911), 132.

[75] Griffin, M. S., *Journ. Am. Chem. Soc.* (1899), 21, 676.

occurs in all boilers not protected with a scale or other coating. All natural waters contain oxygen, and this, introduced with the feed water, may attack any unprotected iron with which it comes in contact. This action may be especially marked at the feed-pump discharge. Corrosion resulting from this factor may take the dangerous form of pitting, due to the accumulation of air in pockets. Ost [76] ascribes the oxidation of the iron, in part, at least, to the decomposition of the hot feed water.

"Iron cannot rust in water unless oxygen is present." [77] Oxygen accelerates corrosion by removing the protective film of hydrogen, which is the product of electrolytic action. The removal of the oxygen from the feed water before it enters the boiler is, therefore, to be recommended. This is accomplished preferably by means of an open preheater or by various chemical methods, such as an alkaline tannin solution.

Corrosion may be due to galvanic as well as to chemical action. If there is any difference of potential between the parts of a system immersed in an electrolyte, an electrochemical action will be set up. Two dissimilar metals in an electrolyte, and in electrical contact, will start such an action, in which the more electropositive metal will be worn away. Thus copper or brass feed pipes in contact with iron will set up an electrochemical action at the expense of the more electropositive iron. Iron may itself set up electrolytic couples even if it is not segregated, owing to physical strains occasioned by previous heat treatment.[78]

Dissimilarity of metals is not an essential condition for electrochemical action. Unequal stress, distortion, or temperature in different parts of the same piece of metal or lack of homogeneity may give rise to differences of potential.

It has been often observed that brass steamship propellers corrode most rapidly near the propeller shaft. This is frequently due to the fact that there is a greater strain at that point than at the edges, when the propeller is in motion. A difference of potential is thus set up and electrolysis takes place, in which the center of the propeller is anodic and is consequently corroded.

[76] Ost, H., *Chem. Zeitg.* (1902), 26, 820.

[77] Cushman, A. S., and Gardener, H. A., The Corrosion and Preservation of Iron and Steel (1910) 101.

[78] Buergess, C. F., Boiler corrosion as an electrochemical action, *Journ. Western Soc. Eng.* (1909), 14, 375.

The attention of the Bureau of Science was recently directed to some very badly corroded copper fire tubes in a number of locomotive boilers. These copper tubes were used in conjunction with a number of small brass fire tubes, all being embedded in a copper fire sheet at one end and in an iron end-sheet at the other. The corrosion of the copper tubes occurred where they were embedded in the fire sheet, the brass tubes and iron end-sheet showing little or no corrosion. Potential measurements made with a millivoltmeter while the boiler was in operation showed differences of potential between different parts of the copper tubes, as well as between different parts of the system copper-brass-iron. The copper tubes at the points of greatest attack were anodic to all other parts of the system. Here the phenomenon was thermoelectric.

Stray currents are frequently the cause of corrosion. This is true particularly in tropical regions, where proper insulation is made exceedingly difficult by the saturated condition of the ground during the long periods of continuous rainfall. Many cases of excessive boiler corrosion observed in Manila have been accompanied by appreciable differences in potential between the boiler parts and the surrounding objects.

Several methods have been suggested and some successfully adopted, for the prevention of electrolytic corrosion. They are all based on the fact that iron will be corroded only when it is the anode. Any method, therefore, that makes iron the cathode, will bring about the desired result. Zinc, which is electropositive to iron, is often connected to iron. As iron is cathodic to zinc, it is thus protected from corrosion. Many cases have been recorded where zinc has been employed very satisfactorily in this way to protect boiler parts and condenser tubes. However, it must be remembered that the protective influence of zinc extends only over short distances and that the zinc dissolves rapidly and must be replaced. In some cases, too, a non-conducting adherent coating of zinc salts is formed, which decreases the protective action. If this coating is of zinc oxide, corrosion may be even greatly accelerated, instead of inhibited, due to the fact that zinc oxide is cathodic to iron.[79] Aluminium has been suggested as a substitute for zinc. Until a satisfactory method has been devised for its application, however, it is open to even greater objection than the zinc, as a coating of aluminium oxide forms quickly and is very adherent.

[79] Friend, J. Newton, op. cit. (1911), 266.

Another proposal that has been made[80] is to make iron the cathode by impressing a counter electromotive force from storage batteries or a small dynamo. In the absence of any depolarizer, dissolved oxygen especially, a very small current should produce an electromotive force large enough to neutralize the tendency of the iron to pass into solution. The density of the current required can be calculated, within the limit of experimental error, from the loss in weight of the unprotected metal under the given conditions. For boiler protection, a rod of iron or carbon connected to the positive pole of a dynamo serves as the anode, the other pole being the boiler plates or tubes. A number of successful applications of this treatment have been recorded.

Still another suggestion to prevent corrosion is to passivify the iron. Certain chemicals, notably oxidizing agents, render iron passive and resistant to the ordinary forms of attack. It has been calculated that the addition of 1 kilogram of potassium dichromate to 12.5 metric tons of water would prevent corrosion.[81] This procedure, however, cannot be recommended for general practice, because, under certain conditions, oxidizing will increase, not inhibit, corrosion. For a very pure water, passivity will take place in a bichromate solution $\frac{1}{160}$ normal,[82] and corrosion should be inhibited. In the presence of salt a reaction takes place, whereby an acid is formed, in accordance with the equation:[83]

$$H_2O + K_2Cr_2O_7 + 2NaCl \leftrightharpoons K_2CrO_4 + Na_2CrO_4 + 2HCl.$$

The hydrochloric acid formed not only may be expected to destroy the passivity of the iron, but it also attacks it, so that corrosion would be greatly accelerated. Furthermore, in the presence of free acid, potassium bichromate does not passivify iron, but instead actually accelerates corrosion, because of its strong depolarizing effect—that is, by the removal of hydrogen. This accelerated corrosion has been determined experimentally by Watts.[84] Recent experiments in this laboratory have shown that under certain conditions the corrosion of iron in acid solution may be proportional to the concentration of bichromate.

The most general boiler trouble experienced in the Philippines,

[80] Clement and Walker, *Tech. Paper, U. S. Bur. Mines* (1913), No. 15.

[81] Cushman, A. S., *Bull. U. S. Dept. Agr.* (1907), No. 30.

[82] Cushman, op. cit.

[83] Friend, J. N., *Journ. Iron Steel Inst.* (1908), 2, 9, quoted by Friend, J. N., Corrosion of Iron and Steel (1911), 163.

[84] Watts, O. P., *Trans. Am. Electrochem. Soc.* (1912), 21, 232.

however, is the formation of scale. The limestone formation, so common in the Islands, gives rise to a large number of waters with high calcium and magnesium contents. In other sections the volcanic origin of the land surface and the nature of the secondary formations are shown in high sulphate concentrations.

Scale is caused by the deposition of suspended or dissolved material within the boiler shell or on the tubes and is termed sludge, sediment, or incrustation according to its texture and position. The deposition of the dissolved material at the high boiler temperature may be due to reduced solvent properties, to chemical action and precipitation, or to the concentration and crystallization that accompany the evaporation of the feed water. Mud, other suspended matter, and a portion of the dissolved organic matter may be baked into an adherent coating, which will be soft or hard, depending on the nature of the other scale-forming ingredients in the feed water.

Calcium and magnesium are almost always the predominating basic substances in scale and, in the form of carbonate and sulphate, ordinarily constitute over 90 per cent of the incrustations. Iron and aluminium, although normally present in Philippine natural waters, are usually in such small amounts as to have practically a negligible effect in scale formation.

As the method of removal of the scale-forming elements is dependent on their nature, it will be necessary to discuss the character of the different calcium and magnesium compounds as they occur in the raw feed water.

The usual distinction made is indicated by the terms "temporary hardness" and "permanent hardness." Under the former head are included those compounds of calcium and magnesium that are more or less completely decomposed and precipitated by simple heating, thereby removing the basic elements. The compounds of calcium and magnesium that cause permanent hardness, however, are not removed by simple heating, and chemical treatment must be resorted to.

Under temporary hardness are included the carbonates and bicarbonates of calcium and magnesium. Normal calcium carbonate is almost insoluble in water, while magnesium carbonate is slightly soluble. In the presence of free carbon dioxide, however, both carbonates are dissolved to a much greater degree, forming the soluble bicarbonate. This condition is met with in nature by ground waters passing, often under pressure, through decaying organic matter or other sources of carbon dioxide and simultaneously or subsequently through limestone

strata. In this way high concentrations of calcium and magnesium bicarbonates may be produced. On the escape or removal of the carbon dioxide, such as effected by heating, the normal carbonates are reformed and precipitated. Simple boiling will precipitate practically all of the calcium carbonate and most of the magnesium carbonate present.

Neither the precipitated calcium nor magnesium carbonate produces a hard scale in the absence of other scale-forming ingredients. Ordinarily a loose, bulky sediment is formed, which may be washed out or blown off.

Permanent hardness is ascribed to the chlorides and sulphates of calcium and magnesium. Magnesium sulphate and chloride and calcium chloride are increasingly soluble with increasing temperatures, so that, obviously, heating will not remove them. Calcium sulphate is unusual in that its solubility diminishes with increasing temperature, and it may, therefore, be precipitated under boiler conditions. It is deposited as fine crystals, which mix with the mud and other scale material to form a very hard, vitrified scale, which can be removed only by chipping.

Magnesium sulphate alone does not form a scale. In the presence of calcium carbonate, however, one of the hardest scales known is formed. Magnesium chloride has no significance in scale formation when alone. The corrosive effects ascribed to it have been discussed.

If the chemical analysis of a feed water is available, the probable amount of scale can be fairly accurately calculated. Stabler [85] has developed a formula in which the analytical results expressed in parts per million may be used to calculate the amount (in pounds of scale per thousand gallons of water) of scale and sludge liable to be deposited on a boiler operated under the usual conditions of modern practice. The formula is:

$$\text{Scale} = 0.00833 \text{ suspended matter} + 0.00833 \text{ colloidal matter } (= SiO_2 + Al_2O_3 + Fe_2O_3) + 0.0107 \text{ Fe} + 0.0157 \text{ Al} + 0.0138 \text{ Mg} + 0.0246 \text{ Ca}.$$

Recalculated to express the amount of scale in kilograms per cubic meter of water, this formula becomes:

$$\text{Scale} = 0.001 \text{ suspended matter} + 0.001 \text{ colloidal matter} + 0.0013 \text{ Fe} + 0.0019 \text{ Al} + 0.00166 \text{ Mg} + 0.00295 \text{ Ca}.$$

The following formula of Stabler's shows in pounds per

[85] *U. S. Geol. Surv., Water Supply Paper* (1911), No. 274, 176.

thousand gallons the probable amount of material that will be deposited as hard scale:

$$0.00833\ SiO_2+0.0138\ Mg+(0.016\ Cl+0.0118\ SO_4-0.0246\ Na-0.0145K).$$

Expressed as kilograms per cubic meter, the formula becomes:

$$\text{Hard scale}=0.001\ SiO_2+0.0166\ Mg+0.001\ (1.92\ Cl+1.42\ SO_4-2.95\ Na-1.74K).$$

Stabler obtains a coefficient of scale hardness by dividing the amount of hard scale by the total scale. From this coefficient "h" he forecasts the nature of the scale as follows:

1. Soft scale: "h" not more than 0.25.
2. Medium scale: "h" more than 0.25, but not more than 0.5.
3. Hard scale: "h" more than 0.5.

Based on the amount of encrusting ingredients, several more or less arbitrary classifications have been suggested for the suitability of waters for boiler purposes. The following scheme [86] is considerably used:

Parts per million.	Class.
Less than 90	Good.
90 to 200	Fair.
200 to 430	Poor.
430 to 680	Bad.
Over 680	Very bad.

The amount of estimated incrustants for use in the above classifications may be conveniently determined as parts per million from Stabler's formula modified as follows:

$$\text{Encrustants} = \text{suspended matter (turbidity)} + \text{colloidal matter} +1.3\ Fe+1.9\ Al+1.66\ Mg+2.95\ Ca.$$

The incrusting ingredients are also sometimes taken as equal to the "soap-consuming power." [87] This method of estimating the scale-forming materials is used as the basis of the following classification of boiler waters, adopted at a meeting of the American Association of Railway Chemists in May, 1887:

Less than 15 grains per gallon (258 parts per million), good.
From 15 to 20 grains per gallon (258 to 344 parts per million), fair.
From 20 to 30 grains per gallon (344 to 515 parts per million), poor.
From 30 to 40 grains per gallon (515 to 697 parts per million), bad.
Over 40 grains per gallon (697 parts per million), very bad.

[86] *Proc. Am. Ry. Eng. & Maint. Way Assoc.* (1904), 5, 595.
[87] Parr, S. W., *Bull. Ill. State Geol. Surv.* (1909), No. 10, 57.

It will be observed that the limiting values in the two tables differ considerably. This is to be expected. The suitability of a water for boiler purposes is dependent on so many factors that a simple method of diagnosis is hardly possible. Series of numerical standards, like those given above, are of value as indications of the quality of a water. The only final criterion, however, is actual trial under working conditions.

SCALE PREVENTION AND WATER SOFTENING

The undesirability of scale in a boiler needs little comment. Rankine[88] states that calcium carbonate conducts heat eighteen times as badly, and calcium sulphate fifteen times as badly, as iron. It is estimated[89] that one-sixth of an inch of scale necessitates the use of 16 per cent more fuel; one-fourth, 50 per cent; and one-half, 150 per cent additional coal. Schmidt and Snodgrass,[90] as a result of their investigations, conclude that the structure of the scale is of as much importance in these heat losses as, or even of more importance than, its thickness or chemical composition, except in so far as the latter affects the structure.

Furthermore a thick scale frequently causes overheating. The heated parts may swell and bulge to a very considerable extent, sometimes even resulting in a fracture. Again cracks may occur in thick scale, allowing sudden contact of the water with the overheated boiler surface, and blistering or cracking or even an explosion may result.

The most obvious remedy for scale formation is the removal of the scale-forming elements before the water enters the boiler. In spite of the logic of this method of treatment, it is common practice to allow the incrusting material to be precipitated in the boiler. Dependence is then often placed on "boiler compounds" or on various mechanical devices to induce the formation of a soft, nonadherent scale or sludge, which can be blown down readily or otherwise removed. Almost without exception, the prevailing practice in the Philipines is to apply feed-water treatment in the boiler itself.

The number of patented processes for the purpose of making the scale loose and bulky is exceedingly great. Among the mechanical methods may be mentioned the use of wires, chains, and brushes, to entangle the deposit. The electrolytic liberation

[88] Quoted by Rideal, S. and E. K., Water Supplies (1915), 142.
[89] Rideal, loc. cit. See also Shealy, E. M., Steam Boilers (1912), 287.
[90] *Bull. Univ. Ill.* (1907), 4, No. 15, 1.

of hydrogen from the boiler surface to remove scale has been attempted, but without coming up to expectations.[91]

Kerosene, paraffin oil, and substances containing tannin, such as wood extracts, have been successfully used to keep the scale in a loose and pulverized form, in which condition it may be readily blown off. These materials enter into a large number of commercial boiler compounds. Grease of any kind is to be avoided, because it is hydrolyzed and decomposed at high temperature, and acids may be formed that will corrode the iron. In some cases where tallow is used the scale has been found to contain from 12 to 26 per cent of iron from the boiler plates.

The removal of scale-forming ingredients from a water is technically known as "water-softening." It cannot be too strongly emphasized that this process should be carried on outside the boiler. Much of the money spent on mechanical devices for scale prevention would yield better interest if used in preliminary water softening. It is still largely the custom, however, to soften water within the boiler and to remove the precipitated material in the most convenient method possible.

The removal of temporary hardness is comparatively simple, and may be effected by heating, by chemical treatment, or by a combination of the two procedures. The heating process is best carried out in an open feed-water heater, by which the water is raised to the boiling point, when nearly all of the carbonates and a portion of the sulphates are precipitated. The sediment is easily removed from an open heater, while the pipes of a closed heater are soon clogged up and cleaned with difficulty. Another advantage of the open heater is that the escape of the dissolved gases is facilitated, quickening the precipitation of the scale-forming material and lessening the corrosive tendencies of the water.

Nearly all of the calcium carbonate and most of the magnesium carbonate are thus precipitated.

The same result may be achieved by the addition of an alkali, such as milk of lime or caustic soda. As the former is much cheaper and adds no soluble salt to the treated water, it is generally used. In this case the reactions may be represented by the following equations:

$$Ca(HCO_3)_2+Ca(OH)_2 \rightarrow 2CaCO_3+2H_2O.$$
$$Mg(HCO_3)_2+Ca(OH)_2 \rightarrow MgCO_3+CaCO_3+2H_2O.$$

The second reaction does not proceed to completion with the theoretical amount of lime, due to the solubility of the magnesium

[91] Rideal, op. cit., 143.

carbonate. A further amount of lime is, therefore, added to precipitate the magnesium as the more insoluble hydroxide.

The removal of permanent hardness is about nine times as costly as that of temporary hardness. As has been stated, calcium sulphate may be removed by heating under pressure, but as such heating is done preferably outside the boiler, this method of removal is uneconomical. Accordingly chemical treatment is employed.

Calcium sulphate is removed by the addition of soda ash (sodium carbonate) according to the equation:

$$CaSO_4+Na_2CO_3 \rightarrow CaCO_3+Na_2SO_4.$$

Soda ash is the most important ingredient of many boiler compounds.

Magnesium sulphate, which cannot be completely precipitated as the carbonate, is more completely precipitated as the less soluble hydrate by the addition of both lime and soda ash:

$$MgSO_4+Na_2CO_3+Ca(OH)_2 \rightarrow Mg(OH)_2+CaCO_3+Na_2SO_4.$$

The lime-soda process is fairly efficient and comparatively cheap and is the method most extensively employed for water softening. The proper amounts of reagents calculated, the amount of scale-forming ingredients, are added to the feed water, either hot or cold, and the precipitate is allowed to settle. This settling takes place more rapidly with hot than with cold water. After the sediment has subsided, the clear water is withdrawn and conducted to a storage tank. A vertical type of water softener provides a small chemical tank on top of the softener proper, a mixing chamber, and a storage space for the softened water. The chemicals are introduced with the raw feed water into the mixing chamber by an automatic proportioning device. After precipitation has taken place, the treated water flows downward through a quartz filter into the storage space below.

The amounts of lime and soda ash required to soften a water can be determined from its chemical analysis. According to Stabler [92] the number of pounds of lime (90 per cent CaO) and soda ash (95 per cent Na_2CO_3) required per thousand gallons of water may be calculated from the following formulas:

Lime required $=0.00931\ Fe+0.0288\ Al+0.0214\ Mg+0.258\ H$ (from mineral acidity) $+0.00426\ HCO_3+0.0118\ CO_2$.

[92] Stabler, H., *U. S. Geol. Surv., Water Supply Paper* (1911), No. 274, 170.

Soda ash required$=0.0167$ Fe$+0.0515$ Al$+0.0232$ Ca$+0.0382$ Mg$+0.462$ H-0.0155 $CO_3-0.00763$ HCO_3.

Recalculated to express the lime and soda requirements in terms of kilograms of the reagent per cubic meter of water, these formulas become:

Lime required $= 0.001117$ Fe $+ 0.003456$ Al $+ 0.002568$ Mg $+ 0.030960$ H$+0.000511$ $HCO_3+0.001416$ CO_2.

Soda ash required$=0.002004$ Fe$+0.006180$ Al$+0.002784$ Ca$+ 0.004584$ Mg$+0.055440$ H-0.001860 $CO_3-0.000917$ HCO_3.

A negative value for the second formula shows that no soda ash is required.

A rapid chemical method [93] for determining the lime and soda requirements is the treatment of a definite quantity of the water first with a standard calcium hydroxide solution and again with a standard sodium carbonate solution, ascertaining by titration with acid in each case the amounts of alkali consumed.

Considerable attention has been recently directed to the navy standard boiler compound, developed in the United States Navy. The ingredients are sodium carbonate, starch, tannic acid, and trisodium phosphate. The purpose of the sodium carbonate is to take

> Care of any chemical reaction and render the solution noncorrosive. The tannic acid and starch are added to prevent the formation of scale, the action being to hold the impurities in suspension in the colloidal state. The trisodium phosphate prevents the rise of the surface tension of the solution and consequent priming caused by the impurities in the water and by the application of the other ingredients in the compound.

In using this compound, the proportions of the ingredients are varied according to the composition of the raw water. To prevent corrosion,

> A sufficient quantity must be added to each boiler to render the alkaline strength of the water in the boiler 3 per cent of normal or above, and the alkaline strength must be maintained in each boiler.[94]

The precipitated material is easily blown off or washed out of the boiler. A number of instances of successful applications of this treatment have been recorded.

Among the other methods of water softening the "permutit" process deserves special mention. Dr. Robert Gans, of Berlin,

[93] Standard Methods for the Examination of Water and Sewage. American Public Health Association, 755 Boylston Street, Boston, 2d ed. (1915), 69–70.

[94] Babcock, Allen H., A novel method of handling boilers to prevent corrosion and scale, *Journ. Am. Soc. Mech. Eng.* (1916), **38**, 530.

in the course of his geological researches, observed that certain members of the group of rock minerals called zeolites had the property of softening waters that passed over or through them.

In 1906 Gans patented a process for the synthetic production of zeolites. The following is an empirical formula for the material now sold commercially as permutit:

$$2SiO_2 \cdot Al_2O_3 \cdot Na_2O \cdot 6H_2O.$$

When a water containing calcium or magnesium compounds is passed through a porous filter or mass of this sodium-permutit (which is insoluble in water), the sodium in the permutit is replaced by the calcium or magnesium. Thus calcium sulphate, in passing through a filter of permutit, would be converted to sodium sulphate, the calcium remaining behind, forming a calcium permutit, also insoluble. By regulating the flow according to the capacity of the filter, water of zero hardness may be obtained. The material is regenerated by passing through it a 10 per cent solution of common salt, whereby the calcium is replaced by the sodium and passes out as calcium chloride. Commercial installations of permutit have been made both in the United States and in Europe, and one for feed-water softening has been recently ordered by a large factory in the Philippines.

Related to permutit are the Allagit and the Reichling processes, which consist in passing the raw feed water through a filter of rocky material, which removes the scale-forming ingredients.

From the foregoing it will be seen that the characteristics of a good boiler water are freedom from acidity; absence of sulphates and magnesium salts; low concentrations of calcium compounds, suspended and colloidal matter, and dissolved gases; and the presence of only small amounts of sodium and potassium salts.

How hard a water may be used without treatment is decided most practically by a comparison of the cost of artificially softening the water with the savings effected by the use of the softened water.

The benefits of softening include:[95] Saving in boiler cleaning, in boiler repairs, and in fuel due to decrease in scale; fewer idle boilers; decreased depreciation of boilers; value of materials removed by softening plant; and reduced liability to accident and involved losses.

[95] Slightly modified from Aubert and Rogers, Industrial Chemistry for the Student and Manufacturer (1913), 52.

152918——5

The cost of softening includes: Labor and power for operating softener; softening chemicals; interest on cost of installation, depreciation of softening plant; and waste in changing water due to increased foaming tendency of the water.

While it is almost invariably true that practically any cost of treatment will pay returns on the investment, the fact must not be overlooked that there are certain waters which should never be used for boiler purposes, and which no treatment can render suitable for such purpose. In such cases the only remedy is the securing of other feed supply or the employment of evaporators for distilling the feed water as in marine service.[96]

WATER FOR OTHER INDUSTRIAL PURPOSES

Besides its use for steam making, water plays a most important rôle in the industries, not only in the process of manufacture, but often as part of the finished product.

While, in general, the qualities most desired in a water for industrial purposes are softness and freedom from suspended matter, there are certain industries for which waters of a particular composition are the most suitable. Water that is entirely unsuited for one manufacturing process may be very desirable for another. Waters containing sodium chloride are undesirable for soap making, yet are sometimes decidedly advantageous in brewing. Hard waters entirely unsuited for laundry or boiler use may be quite suitable for irrigation purposes. Waters containing calcium and magnesium sulphate, adaptable to brewing, are undesirable for soap making or boiler use.

In the making of beverages and other food products, not only must the water be chemically satisfactory, but it must be hygienically acceptable. Typical cases in the Philippines are found in the preparation of carbonated water products, which have been already discussed, and the manufacture of ice. In connection with the latter, it should be remembered that artificial ice contains all the impurities of the bulk of water from which it was made, this being frozen entire. In the formation of natural ice, on the other hand, the impurities remain in the fluid portion. Cummings[97] found in natural ice exceedingly small amounts of solid residue, usually below 10 parts per million. He further observed a very large reduction in the bacterial content of the ice as compared with that of the water from which it was formed. In three cases this reduction was from 12,000 to 125, 520 to 3, and 1,400 to 10, respectively.

[96] Babcock & Wilcox Co., Steam: Its Generation and Use (1913) 100.
[97] Cummings, H. S., *Journ. Am. Med. Assoc.* (1916), 67, 751.

While in the Philippines distilled and artesian waters are used almost exclusively in the manufacture of artificial ice, an impure and unwholesome product sometimes results from the careless handling of the initially pure water. Though bacteria usually die rapidly in ice, undue reliance should not be placed on this form of self-purification.

The effect of the substances commonly found in water on a number of the industries will be discussed under interpretation of analyses.

The Filipinos are primarily an agricultural people. The two principal crops in the Philippines that require any great amount of cultivation are rice and sugar cane; both of these, especially the former, require much water for their development. Irrigation has been long known in the Philippines in connection with rice culture; it reaches a remarkable stage of development in the wonderful terraced paddies of the Ifugaos and other non-Christian tribes of northern Luzon.

While hitherto the rains have been relied upon to supply the water necessary for the growth of sugar cane, irrigation is coming into use in those localities where it can be employed.

The question of the desirability of a water for irrigating purposes has always been an important one. Surface waters are naturally most commonly used, due to their availability and to the comparatively small effort involved in their employment. In some localities spring waters, when available and of desirable quality, are used to a considerable extent. In other places, notably in certain districts in the western part of the United States, the surface waters have been of such poor quality as to necessitate the perforation of deep artesian wells at great expense. In the Philippines surface waters are most extensively employed, though, in the case of "wet weather" streams, the water is oftentimes available only in the rainy season. Spring waters are also used, but to a less extent. The drilling of artesian wells to supply water for agricultural purposes is not practiced in the Philippines.

The commonest deleterious substances in irrigating waters are salts of the alkalies, notably the carbonates, chlorides, and sulphates of sodium and potassium. Calcium and magnesium carbonates are seldom present in objectionable amount, both because of the fact that even very high initial concentrations are usually lowered by aëration and removal of carbon dioxide and because the addition of these carbonates very often has a beneficial fertilizing action.

The cost of softening includes: Labor and power for operating softener; softening chemicals; interest on cost of installation, depreciation of softening plant; and waste in changing water due to increased foaming tendency of the water.

While it is almost invariably true that practically any cost of treatment will pay returns on the investment, the fact must not be overlooked that there are certain waters which should never be used for boiler purposes, and which no treatment can render suitable for such purpose. In such cases the only remedy is the securing of other feed supply or the employment of evaporators for distilling the feed water as in marine service.[96]

WATER FOR OTHER INDUSTRIAL PURPOSES

Besides its use for steam making, water plays a most important rôle in the industries, not only in the process of manufacture, but often as part of the finished product.

While, in general, the qualities most desired in a water for industrial purposes are softness and freedom from suspended matter, there are certain industries for which waters of a particular composition are the most suitable. Water that is entirely unsuited for one manufacturing process may be very desirable for another. Waters containing sodium chloride are undesirable for soap making, yet are sometimes decidedly advantageous in brewing. Hard waters entirely unsuited for laundry or boiler use may be quite suitable for irrigation purposes. Waters containing calcium and magnesium sulphate, adaptable to brewing, are undesirable for soap making or boiler use.

In the making of beverages and other food products, not only must the water be chemically satisfactory, but it must be hygienically acceptable. Typical cases in the Philippines are found in the preparation of carbonated water products, which have been already discussed, and the manufacture of ice. In connection with the latter, it should be remembered that artificial ice contains all the impurities of the bulk of water from which it was made, this being frozen entire. In the formation of natural ice, on the other hand, the impurities remain in the fluid portion. Cummings[97] found in natural ice exceedingly small amounts of solid residue, usually below 10 parts per million. He further observed a very large reduction in the bacterial content of the ice as compared with that of the water from which it was formed. In three cases this reduction was from 12,000 to 125, 520 to 3, and 1,400 to 10, respectively.

[96] Babcock & Wilcox Co., Steam: Its Generation and Use (1913) 100.
[97] Cummings, H. S., *Journ. Am. Med. Assoc.* (1916), 67, 751.

While in the Philippines distilled and artesian waters are used almost exclusively in the manufacture of artificial ice, an impure and unwholesome product sometimes results from the careless handling of the initially pure water. Though bacteria usually die rapidly in ice, undue reliance should not be placed on this form of self-purification.

The effect of the substances commonly found in water on a number of the industries will be discussed under interpretation of analyses.

The Filipinos are primarily an agricultural people. The two principal crops in the Philippines that require any great amount of cultivation are rice and sugar cane; both of these, especially the former, require much water for their development. Irrigation has been long known in the Philippines in connection with rice culture; it reaches a remarkable stage of development in the wonderful terraced paddies of the Ifugaos and other non-Christian tribes of northern Luzon.

While hitherto the rains have been relied upon to supply the water necessary for the growth of sugar cane, irrigation is coming into use in those localities where it can be employed.

The question of the desirability of a water for irrigating purposes has always been an important one. Surface waters are naturally most commonly used, due to their availability and to the comparatively small effort involved in their employment. In some localities spring waters, when available and of desirable quality, are used to a considerable extent. In other places, notably in certain districts in the western part of the United States, the surface waters have been of such poor quality as to necessitate the perforation of deep artesian wells at great expense. In the Philippines surface waters are most extensively employed, though, in the case of "wet weather" streams, the water is oftentimes available only in the rainy season. Spring waters are also used, but to a less extent. The drilling of artesian wells to supply water for agricultural purposes is not practiced in the Philippines.

The commonest deleterious substances in irrigating waters are salts of the alkalies, notably the carbonates, chlorides, and sulphates of sodium and potassium. Calcium and magnesium carbonates are seldom present in objectionable amount, both because of the fact that even very high initial concentrations are usually lowered by aëration and removal of carbon dioxide and because the addition of these carbonates very often has a beneficial fertilizing action.

Land would probably be injured by the best of natural waters if irrigated with them for a long period of time without natural or artificial drainage, for all irrigating waters contain alkali, and evaporation in and from the soil would result in a gradual accumulation of toxic salts.[98]

Loughridge[99] found the relative toxicities of the alkalies toward common cultures of bacteria to be about as follows:

	Toxicity.
Sodium as Na_2CO_3	10
Sodium as $NaCl$	5
Sodium as Na_2SO_4	1

The investigations indicate further that about 1,680 kilograms per hectare (1,500 pounds per acre) of sodium with a relative toxicity of 1 (as above) in 1.2 meters (4 feet) of soil is barely sufficient to affect injuriously the more sensitive common crops. Stabler used these and other similar experimental data as a basis for the calculation of an alkali coefficient that may be made from a water analysis by the means of the following formulas:

(a) When Na—0.65Cl is zero or negative,

$$\text{alkali coefficient } K = \frac{2040}{Cl}.$$

(b) When Na—0.65Cl is positive, but not greater than $0.48SO_4$,

$$\text{alkali coefficient } K = \frac{6620}{Na + 2.6Cl}.$$

(c) When $Na - 0.65Cl - 0.48SO_4$ is positive,

$$\text{alkali coefficient } K = \frac{662}{Na - 0.32Cl - 0.43SO_4}.$$

Based on the values of the alkali coefficients thus obtained, the following approximate classification of irrigating waters is given:

Alkali coefficient.	Class.
More than 18	Good.
18 to 6	Fair.
5.9 to 1.2	Poor.
Less than 1.2	Bad.

[98] Stabler, Herman, *U. S. Geol. Surv., Water Supply Paper* (1911), No. 274, 177.

[99] Stabler, loc. cit.

MINERAL WATERS

The term "mineral water" is somewhat confusing. Practically all natural waters contain dissolved mineral matter and might be properly classified as mineral waters. However, in the more restricted meaning of the term, only those waters are included that have peculiar characteristics distinguishing them from ordinary spring or well water. According to Grünhut,[100] a mineral water is identified by (a) a high content of soluble matter, (b) a high content of rare or unusual substances, or (*c*) a high temperature. Table III shows the substances on the basis of which he makes his classification and the limiting values for each substance:

TABLE III.—*Grünhut's basis for classification of mineral water.*

Substance.	Parts per million.
Total solids	1,000
Free carbon dioxide	250
Lithium (Li)	1
Strontium (Sr)	10
Barium (Ba)	5
Ferrous or ferric iron (Fe)	10
Bromine ion (Br)	5
Iodine ion (I)	1
Fluorine ion (F)	2
Arsenic (As)	1.05
Total sulphur (S)	1
Metaboric acid (HBO_2)	5
Alkalinity	400
Radium emanation	3.5 Mache units per liter.
Temperature	20° C.[a]

[a] Obviously this value could not be used in a country like the Philippines, where in many localities the average temperature is much higher and water is usually from 25° to 30°C.

If any of these values[101] is exceeded, the water may be regarded as a mineral water.

Mineral waters are further classified on the basis of the ingredients that give them their predominant characteristics. One of the best systems of classification is that of Haywood and Smith,[102] which is generally used in technical work. A simpler,

[100] Grünhut, L., *Zeitschr. f. Balneol.* (1912), 4, 433–6; *Wasser u. Abwasser* (1912), 5, 417–20; *Pharm. Zentralh.* (1914), 55, 180.

[101] This classification has been adopted by the Verein der Kurorte und Mineralquellen-Interessenten Deutschlands, Oesterreich-Ungarns, und der Schweiz.

[102] Haywood, J. K., and Smith, B. H., *Bull. U. S. Dept. Agr., Bur. Chem.* (1905), 91, 11.

less complete classification, sufficient for the purpose of this paper, is as follows:[103]

I. Thermal. Example, Los Baños springs, Laguna.

II. Carbonated (or bicarbonated).

  1. Alkaline, containing:
    a. Sodium bicarbonate.
    b. Potassium bicarbonate (rarely). Example, Dinalupihan Spring, Bataan.
  2. Magnesium, containing:
    a. Magnesium bicarbonate. Example, Hot Spring, Puerto Galera, Mindoro.
  3. Calcareous, containing:
    a. Calcium bicarbonate. Example, Bolocboloc Spring, Barili, Cebu.

III. Chalybeate (iron, ferruginous).

  1. Containing the sulphate or bicarbonate of iron. Example, Lanot Spring, Ambos Camarines.

IV. Muriated waters.

  1. Containing salts, mainly sodium or potassium chlorides. Example, Mainit Spring, Bontoc.

V. Aperient or sulphated waters.

  1. Containing sodium sulphate (Glauber's salt). Example: Klondike Spring, Benguet.
  2. Magnesium sulphate (epsom salt). Example, Tancalao Spring, Tabaco, Albay.

VI. Bromide and iodide waters.

  1. Containing the bromides or iodides of sodium and potassium. Examples, Maaslom Spring, Cebu. (Few definitely known in the Philippines.)

VII. Sulphuretted or hepatic waters.

  1. Containing sodium or hydrogen sulphide. Example, Sibul Spring, Bulacan.

VIII. Arsenical.

  1. Containing arsenic. Example, Tiwi Spring, Albay.

IX. Lithia.

  1. Containing lithium salts. No good example known.[104]

There are other classes of water, such as iodic, borated, and lithic; but these are not so common, or else their properties are indicated by their names, so that they need not be further discussed here.

It is not the intention to discuss at length the medicinal properties of different Philippine waters. At best, the physiologic action of various ingredients in the minute quantities present in waters must remain in doubt. The curative properties sometimes attributed to various mineral springs appear grossly exaggerated, and it hardly seems plausible that the small amounts

[103] Cf. Rideal, op. cit., 12.

[104] No lithium-bearing minerals have been found in the Philippines.

of mineral salts contained in such waters would have the wonderful power ascribed to them. For example,[105]

Though it is true that many drugs are as efficient when given in very small, but frequent doses, as when given in one large dose, the therapeutic value of 1 part per millon of lithium (the amount present in some waters widely advertised as lithia waters) may well be questioned, because a physician would have to prescribe 200 tumblerfuls of the water in order to administer an ordinary minimum dose.

No doubt the pleasant surroundings of the average medicinal spring resort, combined with fresh air, good food, and general relaxation and exercise, contribute their share toward the improvement in the health of a patient and help make possible the remarkable cures often recorded.

Our experience in the Philippines has shown that little reliance can be placed on popular opinion as a criterion of the value of mineral waters. Springs supposed to be of great medicinal value have been frequently found to be of very ordinary chemical content, whereas many waters that compare favorably with those of well-known baths and springs in foreign countries are regarded with complete indifference. A certain town has an artesian water very similar chemically to that of Sibul Springs, yet there was, until a short time ago, a decided antipathy to its use. Very recently wonderful curative properties were attributed to a certain artesian well, and hundreds of people traveled many kilometers to partake of its waters; yet this water is in many respects similar to a supply in another province that people frequently refuse to drink. Observations were made on one of the best-known and most popular springs a short time ago,[106] with some curious results:

In order to ascertain whether the water has laxative or constipating properties a record was kept of a large series of cases for the effect which water had upon persons who visited there, with the result that diarrhœa was produced in approximately one-third of the people, constipation in another third, and the remaining third was apparently unaffected in so far as action of the bowels was concerned.

However, the value of mineral waters is now so generally accepted that their use has become firmly established in therapeutic practice. The following statement of the medicinal values [107] of different classes of mineral waters is taken directly from Haywood and Smith.[108]

[105] Dole, *U. S. Geol. Surv., Water Supply Paper* (1910), No. 254, 25.

[106] *Ann. Rep. P. I. Bur. Health* (1913), 32.

[107] Compare also the statements on the effect of various ingredients in the chapter on Interpretation of Water Analyses.

[108] Op. cit., 12.

The physiological action and therapeutic applications of the various classes of mineral waters here given do not represent the results of experiments carried on in the Bureau of Chemistry, but are gathered from works which are considered authoritative on the subject.[a]

[Footnote: [a] Among these are Crook's Mineral Waters of the United States and Canada, Schweitzer's Mineral Waters of Missouri, and Cohen's System of Physiologic Therapeutics.]

Carbonated or bicarbonated alkaline waters.—This is one of the most important groups of mineral waters. As a class these waters are used to stimulate the secretions of the digestive tract, neutralize superacidity of the stomach, increase metabolism, dissolve uric acid, increase the flow of urine, correct acidity of the urine, and dissolve uric acid deposits. They are therefore of value in catarrhal conditions of the mucous membranes, rheumatism, gout, diabetes, etc.

Sodic carbonated and bicarbonated alkaline waters.—Sodium carbonate or bicarbonate appears as a normal constituent of the blood, lymph, and nearly all secretions of the mucous membrane. Where conditions arise that cause any of these fluids to become acid, this class of waters is of great value in counteracting the effect. The sodic carbonated waters increase metabolism, dissolve uric acid, and allay irritation of the mucous membrane of the urinary tract. They have therefore been used with excellent results in treating acid dyspepsia, rheumatism, gout, and diabetes. Such waters are also of value in breaking up and eliminating uric acid deposits and uric acid sand and gravel.

Potassic carbonated and bicarbonated alkaline waters have very much the same action as the sodic carbonated, except that they are perhaps better for increasing the solubility and elimination of uric acid. The chief use of such waters as these is in the treatment of stone in the bladder.

Lithic carbonated and bicarbonated alkaline waters.—While lithium seldom or never occurs in waters in large enough quantities to be a predominating basic constituent, still it does often appear in sufficient quantities to have a decided therapeutic action. These compounds are active diuretics and form a very soluble urate which is easily eliminated from the system. Waters of the above class therefore find their greatest application in the treatment of rheumatism, rheumatic tendencies, and gout. In cases of gravel and calculi they are also valuable disintegrating agents.

Magnesic carbonated and bicarbonated alkaline waters.—Such waters as these act as mild laxatives and are perhaps the best of all the carbonated alkaline waters in correcting an acid condition of the stomach and curing sick headaches caused by constipation. They favor the solution of uric acid, are valuable agents in breaking up deposits in the bladder, and are much used in catarrhal conditions of the mucous membrane of the urinary organs.

Calcic carbonated and bicarbonated alkaline waters.—This class of waters is quite different in its effect from the carbonated waters previously mentioned. While the foregoing waters are evacuant and promote secretions, this class of waters constipates and decreases the secretions. Very obstinate cases of chronic diarrhea have been cured by a sojourn at a spring rich in calcium bicarbonate. Uric acid gravel and calculi are also disintegrated and eliminated by the free use of the above waters.

Ferruginous bicarbonated alkaline waters.—These waters increase the amount of hæmoglobin and in connection therewith increase the temperature, pulse, and weight. They also increase the appetite and reduce intestinal activity. Such waters give excellent results when used as a tonic. They find their principal application in anæmia and in general debility brought about by sexual diseases. Too long use of waters rich in iron results in constipation and derangement of the digestion.

Borated alkaline waters.—There are comparatively few springs of this description which have been used to any extent. Their therapeutic application, therefore, is somewhat obscure. It may be said, in general, that such waters act as anti-acids. They promote the menstrual flow, and so may be used in catamenial irregularities. Applied locally to catarrhal mucous membranes, they are of value.

Muriated alkaline-saline waters.—These waters are especially valuable in the treatment of catarrhal conditions of the mucous membrane of the stomach, intestines, and biliary passages, and urinary tract. They increase the flow of urine and the excretion of uric acid. The stronger ones are often used as a gargle.

Sulphated alkaline-saline waters.—These waters, like the preceding class, are valuable in the treatment of catarrhal conditions of the mucous membrane. They also act as diuretics. In large quantities they act as purgatives by increasing the peristaltic movement and liquefying the intestinal contents. Such waters as these are especially indicated in obesity.

Muriated saline waters.—As a whole these waters stimulate the secretion of the stomach, increase digestion, favor a more complete absorption of foods, and act as diuretics.

Sodic muriated saline waters.—Where these waters are very heavily charged with sodium chlorid they are often used for baths, to increase the action of the skin, and by absorption act as a tonic. Such waters when taken internally are usually diluted. They increase the flow of gastric juice, improve the appetite, increase the flow of urine, and the urea in the same. They also prevent putrefactive changes in the intestines.

Potassic muriated saline waters.—The authors do not know of any waters which belong to the muriated saline group and yet contain potassium as a predominating constituent. However, potassium is sometimes present in these waters in considerable quantities. Its therapeutic action is very much like that of the sodium salt.

Lithic muriated saline waters.—Such waters as these would have the usual action of the muriated saline class, with an intensified diuretic effect, due to the lithium.

Calcic muriated saline waters.—These waters usually have sodium as the predominating basic constituent, along with notable amounts of calcium and sometimes magnesium. In general debility these waters act as a tonic. They increase the flow of urine, sweat, and bile, and are used in the treatment of scrofulous diseases and eczema.

Sulphated saline waters.—As a class, these waters are laxative or purgative according to the quantity taken, and should generally only be used in moderate amounts. They are especially indicated where long-continued stimulation of the intestinal activity is desired without stimulation of the vascular system.

Sodic and magnesic sulphated saline waters.—In small doses these

waters act as laxatives and in large doses as purgatives. They increase the flow of the intestinal fluids and of the urine, the latter being accompanied by an increased elimination of urea. Such waters as these are of great service in eliminating syphilitic, scrofulous, and malarial poisons from the system and in throwing off mercury and other metallic poisons. Persons suffering from obesity, dropsy, derangement of the liver, and Bright's disease are perhaps the most benefited by this class of waters.

Potassic sulphated saline waters.—While potassium may be present in large enough quantities in the sulphated saline waters to deserve mention, the authors do not know of any waters in which it is a predominating basic constituent. In so far as it is present, however, it has very much the same effect as the two salts mentioned above.

Calcic sulphated saline waters.—This class of waters forms what is known as the permanently hard group. They have no well-known therapeutic action.

Ferruginous sulphated saline waters and aluminic sulphated saline waters.—Iron and aluminum usually occur together when either is present as a predominating metallic constituent in sulphated saline waters. Since waters containing large quantities of iron and aluminum along with sulphuric acid ions are practically always acid, it is best to consider them under the sulphated acid group.

Nitrated saline waters.—The authors have only found one water which belongs to this class, and are undecided, on account of not being able to examine the surroundings of the spring, whether the nitrates are due to organic nitrogenous matter which is in active state of decomposition or to nitrogenous matter which has been oxidized in times long past and is therefore no longer injurious. In either case, however (especially in the latter), the existence of one water containing predominating quantities of nitrates necessitates a classification to cover this group of waters. The medicinal action of these waters has not been determined.

Acid waters.—This group of waters is principally composed of the ferruginous-aluminic sulphated class, although there are a few acid springs which contain comparatively little iron and aluminum, but quite large amounts of calcium, sodium, or magnesium. These waters are used in relaxed conditions of the mucous membrane, especially when characterized by diarrhea or dysentery. These are also used in the treatment of exhausting night sweats and impoverished conditions of the body brought about by intemperance or specific diseases. Locally they are used in treating inflamed or relaxed conditions of the mucous membrane such as are found in conjunctivitis, chronic vaginitis, etc. The ferruginous waters of this group have the usual effect of all iron waters, such as has already been described under ferruginous carbonated alkaline waters. When a water is desired for its tonic effect it is best to give it in the ferruginous carbonated form, since it is more easily absorbed and assimilated.

Iodic and bromic waters.—Since iodin and bromin usually accompany each other in mineral waters, they should be considered together. Waters of this class act as alteratives. They stimulate the lymphatic system to greater activity and promote absorption in all the tissues. Their employment is therefore indicated in the treatment of scrofula, syphilis, goiter, chronic exudations, etc. They also favor the elimination of mercury and other metallic poisons. The bromic waters also act as sedatives.

Arsenic waters.—These waters act as an alterative, increase the ap-

petite and digestion, and improve the whole nutrition of the body. They do this not only by increasing the secretion of the gastro-intestinal membrane, but also by checking katabolism. Such waters as these are especially valuable in the treatment of anæmia and a number of skin diseases. They are also indicated in the treatment of chronic malarial poisoning, neuralgia of anæmia origin, scrofulosis, etc.

Silicious waters.—The medicinal value of these waters has not been thoroughly investigated, althought one or two investigations have been made which seem to show that they would be of value in the treatment of cancer. It has been stated that silica taken internally has caused albumin and sugar to disappear from the urine.

Azotized and oxygenated waters.—Both nitrogen and oxygen are present in all waters that have come in contact with the air. On account of the limited solubility of both they can not occur in waters in very large quantities. Neither of them as they occur in waters has any medicinal value.

Carbondioxated waters.—These waters contain free carbon dioxid as distinguished from the carbonated or bicarbonated waters which contain carbon dioxid in combination. Usually the heavily carbondioxated waters are also bicarbonated, but this is, not necessarily true. Free carbon dioxid is present in practically all natural waters to some extent, but in some waters, notably the Saratoga, it is present in very large quantities. Such waters are extremely palatable and large quantities can be drunk without causing a "full feeling." These waters tend to increase the flow of saliva and intestinal fluids, also to increase the peristaltic movements of the stomach, and therefore increase digestion. They also tend to increase the flow of urine. Obstinate cases of nausea are often relieved by the use of this class of waters.

Carbureted waters.—These waters sometimes occur in coal and natural-gas regions. They are not known to have any medicinal value, but are usually considered unfit for drinking purposes.

Sulphureted waters.—These waters increase the action of the skin, intestines, and kidneys. They also possess a decided alterative effect. They have been used in the treatment of syphilis, chronic metallic poisoning, rheumatism, and gout. They have also given excellent results in many skin diseases, hyperæmia of the liver, and catarrhal conditions of the pharynx, larynx, and bronchi.

The radioactive waters should be added to this list, as these have been frequently found to be of therapeutic value. Because of the importance of this class of waters, they will be discussed under a separate heading.

As a general rule, better therapeutic effect has been obtained by the use of waters directly at the source than when taken at a distance, and this for a variety of reasons. Radioactivity is an evanescent quality, which cannot be conserved by bottling; natural waters are unstable and undergo changes on standing; and above all the physiological effect of imbibing waters at the source is of importance. At considerable distances from desirable sources, however, the use of bottled waters is much practiced.

The cost of softening includes: Labor and power for operating softener; softening chemicals; interest on cost of installation, depreciation of softening plant; and waste in changing water due to increased foaming tendency of the water.

While it is almost invariably true that practically any cost of treatment will pay returns on the investment, the fact must not be overlooked that there are certain waters which should never be used for boiler purposes, and which no treatment can render suitable for such purpose. In such cases the only remedy is the securing of other feed supply or the employment of evaporators for distilling the feed water as in marine service.[96]

WATER FOR OTHER INDUSTRIAL PURPOSES

Besides its use for steam making, water plays a most important rôle in the industries, not only in the process of manufacture, but often as part of the finished product.

While, in general, the qualities most desired in a water for industrial purposes are softness and freedom from suspended matter, there are certain industries for which waters of a particular composition are the most suitable. Water that is entirely unsuited for one manufacturing process may be very desirable for another. Waters containing sodium chloride are undesirable for soap making, yet are sometimes decidedly advantageous in brewing. Hard waters entirely unsuited for laundry or boiler use may be quite suitable for irrigation purposes. Waters containing calcium and magnesium sulphate, adaptable to brewing, are undesirable for soap making or boiler use.

In the making of beverages and other food products, not only must the water be chemically satisfactory, but it must be hygienically acceptable. Typical cases in the Philippines are found in the preparation of carbonated water products, which have been already discussed, and the manufacture of ice. In connection with the latter, it should be remembered that artificial ice contains all the impurities of the bulk of water from which it was made, this being frozen entire. In the formation of natural ice, on the other hand, the impurities remain in the fluid portion. Cummings[97] found in natural ice exceedingly small amounts of solid residue, usually below 10 parts per million. He further observed a very large reduction in the bacterial content of the ice as compared with that of the water from which it was formed. In three cases this reduction was from 12,000 to 125, 520 to 3, and 1,400 to 10, respectively.

[96] Babcock & Wilcox Co., Steam: Its Generation and Use (1913) 100.
[97] Cummings, H. S., *Journ. Am. Med. Assoc.* (1916), 67, 751.

While in the Philippines distilled and artesian waters are used almost exclusively in the manufacture of artificial ice, an impure and unwholesome product sometimes results from the careless handling of the initially pure water. Though bacteria usually die rapidly in ice, undue reliance should not be placed on this form of self-purification.

The effect of the substances commonly found in water on a number of the industries will be discussed under interpretation of analyses.

The Filipinos are primarily an agricultural people. The two principal crops in the Philippines that require any great amount of cultivation are rice and sugar cane; both of these, especially the former, require much water for their development. Irrigation has been long known in the Philippines in connection with rice culture; it reaches a remarkable stage of development in the wonderful terraced paddies of the Ifugaos and other non-Christian tribes of northern Luzon.

While hitherto the rains have been relied upon to supply the water necessary for the growth of sugar cane, irrigation is coming into use in those localities where it can be employed.

The question of the desirability of a water for irrigating purposes has always been an important one. Surface waters are naturally most commonly used, due to their availability and to the comparatively small effort involved in their employment. In some localities spring waters, when available and of desirable quality, are used to a considerable extent. In other places, notably in certain districts in the western part of the United States, the surface waters have been of such poor quality as to necessitate the perforation of deep artesian wells at great expense. In the Philippines surface waters are most extensively employed, though, in the case of "wet weather" streams, the water is oftentimes available only in the rainy season. Spring waters are also used, but to a less extent. The drilling of artesian wells to supply water for agricultural purposes is not practiced in the Philippines.

The commonest deleterious substances in irrigating waters are salts of the alkalies, notably the carbonates, chlorides, and sulphates of sodium and potassium. Calcium and magnesium carbonates are seldom present in objectionable amount, both because of the fact that even very high initial concentrations are usually lowered by aëration and removal of carbon dioxide and because the addition of these carbonates very often has a beneficial fertilizing action.

the hot springs near Manito, across the bay from Legaspi. One of these on the beach is covered at high tide, but at low water it sends up a small column of steam which can sometimes be seen from passing steamships. There are other hot waters and a number of mineral springs in the region of the cordillera, but they are considered of little importance at present.[111]

Batangas.—There are a number of thermal and other mineral springs in Batangas, which, however, have not been much studied. A flowing artesian well at Batangas is worthy of mention (see radioactivity) as the most radioactive source yet found in the Philippines.

Bulacan.—Of the many mineral waters of Bulacan Province, only two have been sufficiently studied to merit description here.

The springs at Sibul are nonthermal, mildly suphureted sources of very great capacity. A splendid bathhouse has been erected here by the Insular Government. People come from great distances for the waters, which have, perhaps, the greatest reputation for medicinal virtues of any waters in the Islands. The usual statements based on the chemical analysis regarding the therapeutic value of these springs are undoubtedly erroneous, as the waters are only moderately mineralized. However, the springs are among the most radioactive yet found in the Philippines.

The artesian well at Marilao has acquired a great reputation, and a bathhouse has been built. The waters are nonthermal and are not sufficiently mineralized to be classed as mineral waters. They are not radioactive. There is no apparent reason why they should be considered medicinal.

Cebu.—At the request of the Speaker of the Philippine Assembly an investigation of the mineral springs of Cebu was conducted by Mr. Gana,[112] of the Bureau of Science. The results of his work are incorporated in Table XII (spring waters).

Cebu has many excellent thermal and mineral springs. Boloc-boloc Spring, at Barili, is nonthermal, sulphureted, bicarbonated, carbon-dioxated. Other sources are "Mainit," Naga, a thermal spring; a nonthermal sulphureted spring at Dumanjug; a hot spring at Malabuyoc; and others, whose analyses are shown in the tabular data.

Iloilo.—Perhaps the best-known springs are those on Guimaras Island. They are chiefly nonthermal, calcic, bicarbonated.

Laguna.—Laguna Province is well supplied with springs,

[111] Adams and Pratt, loc. cit.

[112] Cox, A. J., Heise, G. W., and Gana, V. Q., *Phil. Journ. Sci., Sec. A* (1914), 9, 273.

especially in the vicinity of Mounts Maquiling, Banajao, and San Cristobal.

There are many springs in the neighborhood of Los Baños and on the slopes of Mount Maquiling. A large sanatorium has been erected at the town of Los Baños, which attracts many visitors.

The Los Baños hot springs are only moderately mineralized. They are, however, the most highly radioactive thermal sources known in the Philippines.

Pansol Springs, between Calamba and Los Baños, have no abnormal chemical characteristics. It is popularly believed that they are alternately hot and cold. This erroneous impression is due to the fact that they are really a series of hot and cold springs, of very different chemical composition, which emerge into the same pool of water. These springs are located in a very beautiful grotto.

A large spring, called Bumbungan, is located near Pagsanjan, on the river bank near the famous Pagsanjan gorge. A stone bathhouse, dating back to Spanish times, has been erected. The water is of very ordinary mineral composition and is only very moderately radioactive.

There is a very picturesque spring at Pakil, which flows into a large pool or basin. Medicinal properties are attributed to this source, and religious pilgrimages are made to it. The water is only slightly mineralized and is moderately radioactive.

Among other well-known springs, the following may be mentioned: Sinabac, Majayjay, of ordinary mineral composition but highly radioactive, and a series of moderately radioactive springs of no abnormal chemical characteristics, such as San Diego and San Vicente, Nagcarlan; Baño and Bañadero, San Pablo; and San Mateo, Lilio.

Leyte.—This Bureau has little first-hand information concerning Leyte mineral waters. Adams [113] mentions a number of thermal and cold mineral springs. He says:

> Besides the springs already mentioned as associated with the solfataras on Bilirán Island and near Burauen in Leyte and those related to the extinct volcanoes, Mount Amandiuing and Mount Cabalían, there is a small hot spring on the west side of the point of land which projects from Leyte opposite Poro Island in the Biliran strait and a hot sulphur spring on Mount Ogris south of Mount Nipga between Abuyog and Baybay. South of Abuyog in the barrio Buenavista there is a cold mineral spring. To the west of Alangalang, on the west side of the Cabayong River, there are some small and apparently nearly buried hills which are probably

[113] Adams, G. I., *Phil. Journ. Sci., Sec. A* (1909), 4, 345–6.

outliers of the Cordillera and at the base of one of these there is a cold mineral spring.

Mindoro.—Comparatively little is known of Mindoro. The thermal, sulphureted, sulphated, bicarbonated springs of Puerto Galera may be mentioned in passing. At Calapan there are a few hot and sulphur springs that were used as baths in Spanish times.

Misamis.—Springs in great variety and abundance are found in Misamis.[114]

Mountain Province.—As might be expected in a volcanic, mountainous region, Mountain Province is plentifully supplied with springs. Owing to the difficulty of travel and the backward state of the inhabitants, these springs are comparatively little visited. Only a few of the better known hot and heavily mineralized springs will be mentioned here.

Klondike springs are situated on Benguet Road, on the west bank of Bued River. They are very hot and only moderately mineralized and sulphated.

There is a series of hot, sulphureted springs that have been used for medicinal purposes for many years about a kilometer below Balongabong, or Twin Peaks, on the west bank of Bued River. These springs have a temperature of 50°C.

At Itogon, only 15 to 17 kilometers from Baguio, is a series of hot, heavily mineralized springs, which were once much visited. In recent years a landslide covered some of them and changed the character of others, but they are still capable of development. As they are comparatively close to Baguio, they could be readily utilized.

The hot springs near Cervantes, notably at Comillas, also have a considerable reputation for medicinal virtues.

There is a remarkable series of springs at Kiangan used, in a great measure, for irrigation purposes. Though not characterized by any abnormal chemical ingredients, these springs are highly radioactive. One of these springs (Adukpung) is worthy of more than brief mention. It emerges from the wall of a rice paddy, only a few centimeters below the level of the water in the field, and has all the appearance of a seepage spring. It is asserted, however, that it flows throughout the year, even when the rice paddy is dry. The high radioactivity of this water and the data obtained from its chemical analysis as com-

[114] Rev. Selga, S. J., secretary of the Weather Observatory, recently visited the springs on Camiguin Island and furnished the Bureau of Science with a report, which should be of value when the opportunity arrives to do intensive work on mineral waters.

pared with that of the rice paddy water indicate that it is a true spring. It would be interesting to examine the water-bearing strata at this place.

There are many saline springs, some of which are, or have been, used for salt making. Chief among these are the boiling hot Mainit Spring near Bontoc, whose waters, though used for salt manufacture,[115] are also used for medicinal purposes; Balotoc, 10 kilometers east of Lubuagan, boiling hot and very highly mineralized; and Tukukan, Ahin, and Bungubungua, in Ifugao. Salt making at Amdangle, Ifugao, and at Asin, near Daklan, Benguet, has been discontinued, because landslides have ruined the springs.

Negros.—Springs of many different kinds are common on Negros, but no intensive study of them has been yet made. There is a small sulphureted spring with reputed medicinal properties near Isabela, Occidental Negros. The springs at Mambucal on the sides of Mount Canlaon are very highly prized. Two springs in Oriental Negros are especially worthy of mention, namely, Masaplud, acid aluminic, sulphated, and a thermal saline spring at Palimpinon.

Nueva Vizcaya.—The mineral waters of Nueva Vizcaya have not been intensively studied. The saline spring at Salinas[116] is used for salt-making. This spring issues from the top of a great white mound of calcium salts deposited from the water (Plate XVII). The water is only very slightly thermal.

Palawan.—There is a salt spring at Culion.

Sorsogon.—Many mineral waters are to be found in Sorsogon Province. A hot spring at Bulusan yields ferruginous, bicarbonated, muriated water; a thermal, carbon-dioxated spring is located at Irosin; a "gushing" artesian water at Sorsogon is calcic, bicarbonated.

The foregoing discussion is merely complete enough for the interpretation of the new data presented in this paper. In a country like the Philippines, where large amounts of bottled water are consumed, and almost a hundred thousand pesos' worth is imported annually, mineral waters are an asset whose utilization would be of great economic benefit. An intensive study of Philippine mineral springs should be carried on. The cost of such investigation would be only a small fraction of what is now spent annually for imported waters of no better quality than those available locally.

[115] Cox, A. J., and Dar Juan, T., *Phil. Journ. Sci., Sec. A* (1915), 10, 389.
[116] Cf. Cox, A. J., and Dar Juan, T., ibid., 390.

BOTTLED NATURAL AND CARBONATED WATERS

The use of bottled waters in the Philippines is comparatively widespread. The report of the Bureau of Customs for 1916 showed that the value of imported waters for that year was 80,000 pesos. This was only 8,000 pesos less than the previous year, in spite of war conditions. When it is remembered that the great bulk of the imported waters is consumed in a relatively few port towns, this item becomes of considerable importance. The value of domestic bottled waters is much larger, though exact data are not available.

Several causes contribute to the extensive use of bottled waters in the Philippines. One is the natural fondness of the Filipino for carbonated water products, particularly the flavored ones. Another reason, which applies especially to the larger towns, is the employment of these products in connection with alcoholic beverages. By far the greatest single factor, however, that contributes to such use is the unsatisfactory condition of many of the water supplies and the desire, on the part of the consumer, to obtain a water whose purity is beyond suspicion. As has been previously mentioned, the importance of pure water for drinking purposes was not emphasized until after the American occupation. Manila alone had a municipal water system, and even this often supplied polluted water to the consumers.

In 1900 the military authorities began the construction of a plant in Manila for the manufacture of ice and the distillation of water and for cold storage purposes. In June of the following year the first ice and distilled water were sold. In 1902 the plant was taken over by the Insular Government and constituted the Bureau of Cold Storage. Five years later it became the division of cold stores of the Bureau of Supply, by which designation it is known at the present time.

The use of distilled water for drinking purposes was at first confined largely to the American and European residents, but gradually spread so as to include the wealthier portion of the Filipino population. In 1913 the Bureau of Health suggested the employment of pure artesian water instead of the distilled product, as it was thought the former might be more wholesome

and palatable. Accordingly an artesian well was drilled for the division of cold stores. As water of excellent quality was obtained, the sale of distilled water has been greatly reduced since that time, its use being supplanted in great measure by that of artesian water. The Federal Government still operates distilling plants and distributes large quantities of water, not only in Manila, but in other parts of the Islands in which army posts are found. The Insular Government also operates a similar ice, cold storage, and distillation plant in Baguio, Mountain Province.

Private individuals were quick to follow the example of the Insular Government. Several corporations were formed, a number of artesian wells were drilled, and the sale of artesian and distilled water soon became an important business enterprise. Spring waters, too, received attention, notably those of Sibul and Los Baños.

Several methods of distribution to the consumer have been employed. A few large tank carts are in service. More general, however, is the use of demijohns, holding about 19 liters (5 gallons), and of 1-liter bottles. Water that is initially pure may be unfit to drink when it reaches the consumer, due to unsanitary methods of bottling. Examinations made at the request of the Bureau of Health of samples taken at random from the distribution carts of various companies frequently have shown large numbers of undesirable bacteria and in some instances dangerous pollution. As these waters are not only extensively used by private individuals, but constitute the entire drinking supply of practically all of the hotels, hospitals, clubs, and other public and semi-public institutions as well, their supervision is a matter of vital importance to the public health. The contaminated condition of several of these waters, at various times, has been a real menace to the community.

In 1916, at the request of the manager of one of the largest artesian water companies in Manila, the Bureau of Science investigated the methods of bottling employed in his plant. It was found that in this, as in several similar establishments, steam sterilization for the water containers was relied upon, though the equipment used was entirely inadequate for the purpose. Under the conditions existing, it appeared that thorough sterilization by steam could not be economically practiced. Accordingly a plan of chemical sterilization was devised. This was adopted and installed by two of the largest privately owned artesian water companies in Manila. The method has proved to be very efficient and economical. A detailed dis-

cussion of the process will be found in the Appendix, in the form of a report made by the section of water analysis to the Director of the Bureau of Science in October, 1916.

Outside of Manila the bottling of natural waters is confined almost entirely to a few of the large towns like Cebu, Marilao, Iloilo, and Zamboanga. Several of the United States Army posts, as has been mentioned, supply distilled or artesian water to the inhabitants of the vicinity.

Accurate estimates of the extent to which bottled natural waters are employed in the Philippines cannot be made from the data available, either for the Islands as a whole, or for Manila in particular. It may be said that, even in Manila, the use of these waters has increased steadily, despite the improvements in the city supply. Their sale was at first largely among the American and European residents, but is now general among the better classes of all races.

The division of cold stores, distributor of bottled natural water, sells monthly about 4,500 pesos' worth of artesian and distilled water, principally the former. Of this amount 95 per cent is delivered directly to the consumers throughout the city. Water is supplied at the rate of 1.5 centavos per liter delivered to points in the city and of 1 centavo when sold at the plant. Approximately the same charge is made by the privately operated companies, though the price varies somewhat with the distance from the plant.

The largest privately owned bottling company in Manila has a monthly output of natural and aërated waters valued at about 25,000 pesos, divided almost equally between the two kinds of products. Another large concern distributes each month about 2,300 pesos' worth of bottled natural waters and an amount of carbonated waters of about equal value. A large part of the output of both companies is shipped to provincial districts.

When to these sales are added those of the dozen other water-bottling companies in Manila, an idea may be derived of the large extent to which these table waters are employed.

While, as has been mentioned, the use of bottled natural waters is restricted almost entirely to Manila and a few of the other large towns, bottled carbonated waters are found in the most isolated provincial districts. In the more thickly settled sections almost every center of population has its plant for making "aguas gaseosas," or carbonated waters. The largest and best-equipped of these are located in Manila and in the immediate vicinity. In

some cases they are part of a plant devoted to the bottling of natural waters and use the same water as the latter.

In Manila the operations and products of these plants are subject to careful inspection by the Bureau of Health. Bacteriological purity is required, though no arbitrary standards have been fixed. The use of saccharin as a sugar substitute and of harmful dyes is prohibited.

The carbonated water beverages now being sold in Manila are, generally speaking, of good quality. The bacterial content is usually small, and sometimes it is practically nil. Harmful dyes are rarely encountered, both because of their scarcity and because of the abundance of cheap vegetable dyestuffs. Saccharin, which was commonly used in the past, is now found in less than 1 per cent of the samples examined in the Bureau of Science.

In the provincial districts constant supervision is unfortunately impossible. As a result, the carbonated water products manufactured and sold there are often very undesirable hygienically.

In the course of the sanitary survey of an important provincial town, bacteriological examinations were made of 26 samples of carbonated water products, taken directly from the factories. The average number of bacteria per cubic centimeter was found to be 14,000, while organisms of the *B. coli* group were found in 38 per cent of the samples. In another town 54 per cent of 39 samples showed the presence of organisms of the *B. coli* group. These instances are typical.

The unsatisfactory condition of these products must not be necessarily ascribed to the original quality of the waters employed in their manufacture. Formerly waters from any source were used, rivers and dug wells having a prominent place. The efforts of the Philippine Health Service, however, have resulted in a more or less general abandonment of these undesirable sources, with the substitution of more suitable ones. Nevertheless unwholesome beverages are often produced, even when unquestionably pure water, such as that from flowing artesian wells, is employed in their manufacture.

The root of the trouble, therefore, as in the cases of the bottling plants in Manila, must be sought in the methods of manufacture and handling. The equipment for the manufacture of carbonated water products in the provincial districts is usually very primitive. It is often located in a dirty, poorly lighted room in the rear of a tienda. An exceedingly simple apparatus serves for the generation of carbon dioxide from sodium bicarbonate (baking soda) and sulphuric acid. The bottles are poorly

cleaned, a single rinsing with cold water often sufficing. The bacteriologist who collected samples of soda water in a certain town found that "open well water was used in cleaning the dirty bottles" and that "flies were very numerous." The sirups are poorly made, saccharin being sometimes employed. Instead of "crown" caps, corks are frequently employed, these being inserted and wired without previous sterilization.

Under these conditions it is scarcely surprising that the bacteriological quality of bottled waters is sometimes very poor and that fermentation of the sweetened beverages results in evil-tasting and unsalable products. At the present time the great production and sale of highly polluted bottled waters are a constant menace to health in the Philippines. It is to be hoped that funds will be soon available to provide adequate supervision of the various factories supplying the market, so that only high-grade products of uniform purity may be eventually furnished the public.

It has been found difficult, even in American and European countries, to fix standards for the bacteriological quality of bottled waters. Obst [117] sent out a *questionnaire* to a number of bacteriologists associated with sanitary and allied problems, in an effort to learn their attitude in regard to bacterial tolerance in bottled waters. A variety of answers was secured, varying from the advocation of absolute purity to no rigid standard of any kind. Many considered the presence of *B. coli* the best criterion.

In France, Bonjean [118] has held that it is impossible in practice to bottle a water in a strictly aseptic manner; that the number of germs increases rapidly in the bottle after filling and would not justify the statement "not contaminated;" and that, while *B. coli* might indicate contamination, this germ could gain admission from atmospheric dust at the time of bottling.

Obst [119] aptly remarks that:

> It is reasonable also to assume that when people pay from 2 cents to $30 per gallon for bottled water they expect to obtain a pure, or at least a safe water. * * * Before a person undertakes to operate a water business he should be prepared both in equipment and in operating knowledge to turn out a product free from contamination. This is demonstrated to be commercially possible, without burdensome restrictions, by the number

[117] Obst, M. M., Bacteria in commercial bottled waters, *Bull. U. S. Dept. Agr.* (1916), No. 369.

[118] Bonjean, Ed., The repression of frauds in the bottled water trade, *Ann. Falsifications*, 2, 169–76, through *Chem. Abst.* (1909), 3, 1654.

[119] Op. cit., 2, 3, 6, 7.

of firms already marketing water free from contamination. It is equally evident in the ability of other firms to produce clean water after the need of doing so has been emphasized by court action. * * *

The results clearly show that bottled waters can be made to conform to the requirements of the United States Public Health Service for drinking water furnished upon trains; that is, that not more than one 10 cc sample out of five should show the presence of *B. coli.*

Experience in the Philippines has likewise demonstrated that waters can be profitably bottled under aseptic conditions. The best proof of this is the fact that the two largest bottled-water plants in Manila, employing the methods devised by the Bureau of Science, and mentioned above, are turning out products that are practically sterile. When this desirable degree of purity is so easily attained, it seems only fair to constitute it the standard condition for this class of products.

The Philippines are provided with an abundance of excellent spring and artesian waters comparable in quality with foreign waters of great reputation. Many of them could be bottled, carbonated, and marketed economically. There seems to be no good reasons per se why the local demand could not be practically entirely supplied by home manufacture, thus obviating the payment of relatively high prices for imported waters of no greater intrinsic value.

RADIOACTIVITY OF PHILIPPINE WATERS [120]

In 1896 Becquerel [121] found that uranium salts gave off peculiar radiations, which had the power of affecting a photographic plate, even though the plate was wrapped in black paper. This discovery paved the way for a series of investigations, in the course of which some thirty new elements, the so-called radioactive elements, have been discovered.[122] These elements are characterized by the fact that they give off different types of radiations and that they themselves undergo decomposition during that process. The discovery of the element radium, the typical member of the radioactive series, was reported in 1898.[123]

The high market value of radium, approximately 250,000 pesos per gram, is dependent on the scarcity and importance of the substance and on the extreme care and enormous labor involved in its extraction. Thus the largest American company devoted to the extraction of radium turned out only 14 grams of radium element in a period of about three years. To achieve this production, it was necessary to work about 5,000 tons of carnotite ore. The process of extraction is laborious and expensive and requires expert supervision. Incidentally the ore available in the United States is becoming poorer in quality, according to recent reports, so that it is becoming increasingly difficult to operate. It may be noted, in passing, that the United States Bureau of Mines hopes soon to be able greatly to reduce the cost of radium by the introduction of improved methods of extraction.

In recent years the action of radioactive substances on vital processes has been much studied, with the result that the curative properties of radium are now generally admitted.[124] A quan-

[120] The following is essentially an abstract of papers previously published and presents only a brief synopsis of the work of the Bureau of Science on the radioactivity of water. For complete details of this study, the original papers [Wright, J. R., and Heise, G. W., *Phil. Journ. Sci., Sec. A* (1917), 12, 145; Heise, G. W., ibid., *Sec. A* (1917), 12, 293, 309; and Heise, G. W., *Rev. Fil. Med. y Farm.* (1917), 8, 169–175] should be consulted.

[121] Becquerel, H., *Compt. rend. Acad. sci.* (1896), 122, 420.

[122] Soddy, F., The Chemistry of the Radio-elements. 2d ed. Longmans, Green & Co., London (1914).

[123] Curie, P., Curie, Mme., and Bémont, G., *Compt. rend. Acad. sci.* (1898).

[124] Turner, P., Radium, its Physics and Therapeutics. Wm. Wood & Co., New York (1911).

tity of radium salt has been recently imported to the Philippines by certain doctors to be used in medical work.

The therapeutic value of radioactive substances is believed to be due primarily to the so-called B- and Y-rays. Since radium produces only B-rays of feeble intensity in addition to L-rays, whereas the B- and Y-rays are produced principally by its decomposition products, it is clear that the disintegration products of radium should have therapeutic value.[125]

In addition to the study of the nature and properties of radioactivity and radioactive elements, radioactive investigations have come to include a large amount of work on the radioactivity of natural substances, such as rocks, soils, waters, and air. Not only is such work an important contribution to pure science, but it is also of practical value in its bearing on the geology and the development of natural resources of a country.

Early in the history of radioactive investigations it was discovered that many of the natural waters from different parts of the world showed a high degree of activity. It is not surprising, therefore, that mineral waters that are radioactive should find a place in medicinal practice.[126]

Investigation has shown that this activity was usually due to radium emanation (the first disintegration product of radium) and only in a few isolated cases to actual radium content. The radioactivity of waters can only be effective medicinally imme-

[125] A unique suggestion and one that appears to be of practical importance was made by H. Schlundt in *Trans. Am. Electrochem.* Soc. (1915), 28, 424. To quote his own words:

As the supply of radium increases and its therapeutic uses unfold, its efficient use and distribution will become a matter of growing importance. The distribution of the emanation instead of radium will greatly facilitate its more general use and practically obviate the risk of loss. Speaking then not from the viewpoint of the expert in radium therapy, but as one greatly interested in the conservation of our radium supply, I venture to suggest the establishment of centers for the distribution of radium emanation, that is, radium banks as dispensatories of radium emanation. For example, from a radium preparation containing a gram of the metal, five tubes of emanation each equivalent in the therapeutic value to nearly 200 milligrams of radium can be prepared initially, and then as the emanation accumulates a dose equivalent to 160 milligrams of radium can be separated daily thereafter for a good many years, as the half-life period of radium is nearly two thousand years. The loss of one of these tubes of emanation would be relatively insignificant in comparison with the loss of its radium equivalent.

[126] Curie, Mme. P., Die Radioaktivität, Akad. Verlagsgesellschaft M. B. H. Leipzig (1912), 2, 505–506.

diately after waters issue from the ground, since radium emanation is a gas that can be readily removed from water by shaking or aëration, and like other radioactive substances, it soon decomposes and disappears. In a little less than four days the activity of a water, due to its emanation content, would be normally reduced to half its original value, and at the end of four weeks it would be too slight to be of any significance. These facts serve to explain the phenomenon that certain waters of very ordinary mineral content seemed to possess medicinal properties and, furthermore, that they seemed to lose their therapeutic value when not imbibed immediately after they were taken from the source. This behavior has been repeatedly noted with mineral waters even before their radioactivity was discovered; and it is to be expected, if the medicinal effect of a water is due to radioactivity.

The usual process of bottling does not conserve the emanation content, and since radium is so seldom found in natural waters, it is extremely doubtful if any of the ordinary bottled waters from radioactive springs contain appreciable amounts of emanation. It is obvious that, in order to obtain any benefit from radioactive waters, they must be imbibed directly at their source. Statements regarding bottled waters based on the activity of these waters at the source are generally erroneous and misleading.

In the Philippines there are many springs and deep wells high in radioactivity. In the course of an extensive study during 1916 and 1917 about one hundred twenty-five typical Philippine water supplies, including many of the best-known mineral springs, were tested for radioactivity.[127] Though no water was found whose radioactivity was abnormally high, there were many that were sufficiently radioactive to compare favorably with some of the best-known foreign mineral springs. The work further gave indication of a number of local deposits of radioactive material.

An interesting feature of this study is the fact that there is no apparent connection between the radioactivity of any source and its reputation for medicinal virtues. Many of the waters high in activity are regarded with entire indifference by the people, whereas certain other waters, very highly regarded, showed no abnormal mineral content and were entirely free from activity. Some of the waters, however, such as those of Los Baños and Sibul Springs, with perhaps the greatest reputations, have relatively high activities.

[127] Wright, J. R., and Heise, G. W., *Phil. Journ. Sci., Sec. A* (1917), 12, 145. Heise, G. W., ibid., *Sec. A* (1917), 12, 293.

The radioactivity of a number of typical Philippine waters is shown in Table IV, coupled, for purposes of comparison, with the results of measurements on typical foreign waters. In all cases measurements of activity were made directly at the source, by means of the well-known shaking method of Schmidt.[128] Plate XIX shows the type of apparatus used, as assembled for a field determination. The measurements in the table represent radium emanation content and are expressed in terms of the weight of metallic radium that would remain in radioactive equilibrium with that amount of emanation.

TABLE IV.—*Radioactivity of typical foreign and Philippine spring waters.*

Location.	Source.	Radium emanation. Grams $\times 10^{-12}$ per liter.
Foreign.		
Austria, Bad Gastein	Rudolfs spring	[a]142
Do	Tavern tunnel springs	[a]24,000
England, Bath	King's well	[b]139
England, Buxton		[c]1,100
Japan	Springs	[d]69–13,800
United States of America, Colorado	do	[e]120–4,780
Philippine.		
Batangas, Batangas	Artesian well	2,106
Do	Crater Lake, Taal Volcano	([f])
Bulacan, San Miguel de Mayumo, Sibul Springs	Sibul Springs	1,284
Do	do	1,298
Laguna, Calamba, Pansol	Pansol Springs	negative
Laguna, Los Baños	Hot spring near sanitarium	539
Laguna, Majayjay, Olla	Olla Spring	528
Laguna, Majayjay, Malinao	Sinabac Spring	1,297
Laguna, Nagcarlan	San Diego Spring	526
Laguna, Pagsanjan, Maulauin	Small artesian well	880
Laguna, Pagsanjan, Pinagsanhan	Bumbungan Spring	146
Laguna, Pakil	Baño Spring	365
Laguna, San Pablo	Bañadero Spring	713
Laguna, San Pablo, Maganpun	Baño Spring	606
Laguna, San Pablo, Santa Maria	Años Spring	324
Laguna, Santa Cruz	Artesian well, 459	nil
La Union, San Fernando	Municipal spring	242
La Union, Tomás	Artesian well	trace

[a] Mache, H., and Bamberger, M., *Sitzb. kais. Akad. Wiss.*, Wien., Abt. II-a (1914), **123**, 325–403, through *Chem. Abst.* (1915), **9**, 411.

[b] Masson, I., and Ramsay, W., *Journ. Chem. Soc.* (1912), **101**, 1370–1376.

[c] MacOwen, quoted by Rideal, S., and Rideal, E. K., Water Supplies. Appleton & Co., New York (1915), 11.

[d] Isitani, D., et al. *Proc. Tokyo Math. Physic. Soc.* (1914).

[e] Schlundt, H., *Journ. Phys. Chem.* (1914), **18**, 662.

[f] Tested for radium content only. Negative results with 250 cubic centimeters.

[128] Schmidt, H. W., *Physik. Zeitschr.* (1905), 6, 561–566.

TABLE IV.—*Radioactivity of typical foreign and Philippine spring waters*—Continued.

Location.	Source.	Radium emanation. Grams $\times 10^{-12}$ per liter.
Philippine.		
Mountain, Baguio	Camp John Hay, Cariño Spring	194
Mountain, Banave	Bognakan Spring	381
Do	Kiakop Spring	650
Mountain, Bontoc	Spring adjacent to municipal spring	negative
Mountain, Bontoc, Mainit	Mainit Spring	nil
Mountain, Buguias	Salt spring	nil
Mountain, Cervantes	Hot spring on river bank opposite town	nil
Mountain, Itogon	Hot springs	nil
Mountain, Kiangan	Adukpung Spring	1,325
Do	Adungbu Spring	720
Do	Piko Spring	1,058
Mountain, Klondike	Klondike Springs	trace
Mountain, Mancayan	Spring on Balili trail	114
Mountain, Sagada	Mission Spring	111
Mountain, Sagada, Tetepan	Small spring at Salido	263
Do	Artesian well, Calle Español	137
Nueva Vizcaya, Salinas	Salinas Spring	95
Nueva Vizcaya, Santa Fé	Santa Fé Spring	480
Nueva Vizcaya, Solano	Solano Spring	195
Rizal, Parañaque	Artesian well, plaza	632

The highest radium emanation content encountered in the course of this study was noted in a flowing well in Batangas and was equivalent to 2100×10^{-12} grams of radium. The highest activity in a spring water was equivalent to 1300×10^{-12} grams. It is of interest that this maximum for a spring water was shown by three sources, namely, Sibul Springs, Bulacan; Sinabac Spring, Majayjay, Laguna; and Adukpung Spring in Kiangan, Ifugao, Mountain Province.

In only one Philippine water was any actual radium content found, and in this case it was present in almost negligible quantity.

There was no apparent relation to be drawn between the radioactivity of waters and either their chemical quality or the geology of the strata from which they were obtained.

Although emanation taken into the system by the drinking of water may be different in effect from that applied in the usual medicinal treatment and may further be different in effect from that taken into the lungs by breathing, the following analysis may be of interest:

Assuming that in ordinary respiration the average human

being at rest breathes 7 liters of air per minute or 10.1 cubic meters per day, the emanation thus brought into contact with the human system is 770×10^{-12} curies, if the normal emanation content of the air [129] in the Philippines be taken as a basis for calculation. A person would, therefore, have to drink about three-fourths of a liter of Sibul Springs water or one and one-half liters of Los Baños waters in order to take as much emanation into his system as he secures by ordinary daily respiration alone.

Before leaving this subject, it may be of interest to point out that a recent study [130] of Sibul Springs has shown that the radioactivity of a ground water may be remarkably constant for long periods of time, in spite of comparatively great fluctuations in the quantity of water emitted. This indicates that radioactivity is a constant quality of water and that measurements of radioactivity have more than transitory value.

[129] Wright, J. R., and Smith, O. F., *Phil. Journ. Sci., Sec. A* (1914), 9, 51–77.

[130] Heise, G. W., ibid., *Sec. A* (1917), 12, 309.

QUALITY OF PHILIPPINE WATERS

The work on Philippine water supplies has not progressed sufficiently to justify many generalizations on the quality of waters; and other factors make it appear extremely unlikely that many generalizations can be made, at least for some time to come. The Philippine Archipelago is composed of about a thousand islands, many of which, "continents in miniature," with comparatively small area, must be regarded as units in a study of waters. The heterogeneity of the geologic formations in many parts causes waters from sources very near to each other often to show enormous variations in quality. This variation is found both in surface and in ground waters. Thus a recent examination of the waters of the surface wells within the limits of a small town gave the following results:

TABLE V.—*Chlorine content of surface wells.*

Chlorine content (parts per million).	Wells.
Between 0 and 20	10
Between 20 and 40	11
Between 40 and 60	8
Between 60 and 100	8
Between 100 and 150	2
Over 150	1

Of the forty wells examined, the minimum chloride content was 9.8, and the maximum was 192. The variation in the chloride content of adjacent wells was as great as that of widely separated ones. Similarly in the case of deep wells borings within a short distance of each other may encounter different strata, and the water from them may be markedly different. Two deep wells drilled on the Bureau of Science grounds within 50 meters of each other are different, both in regard to the water-bearing strata from which their supplies are derived and in the quality and quantity of water encountered. The water of well 1 contains 725 parts per million of total solids and 70 parts of chlorine, whereas that of well 2 has 500 parts per million of total solids and 12 parts of chlorine. Three wells in Iloilo (at the Iloilo Electric Company's works), located within about 15 meters of each other and drilled to about the same depth, show similar irregularities, two being approximately similar but differing from the third.

However, so far as our experience goes, there is surprisingly little change in the quality of most waters, considered individually. Leaving out of consideration such factors as the admixture of tidal streams by sea water, changes in water-bearing strata due to earthquakes, the deterioration of well casings, or in general, the contamination of water sources, it may be said that the quality of any water is a definite, constant property of a source over extended periods of time.

In the following discussion an attempt will be made to describe briefly both the quality of the water from various sources and the various factors influencing their composition.

Rain water.—In the Philippines the amount of rainfall varies both with the season and with the location. Many parts of the Islands have a rainfall more or less evenly distributed throughout the year; in other parts most of the rain occurs within a period of three or four months, followed by a season of comparative drought.[131]

As might be expected in an Archipelago like the Philippines, the composition of rain water is greatly influenced by the presence of the ocean. Salt is carried far inland by the winds and is brought down with the rain. A series of measurements made on the rain water collected on the roof of the Bureau of Science [132] for a period of over a year showed a minimum chloride content of 2.2 parts per million, a maximum, during stormy weather, of 19 parts per million, and an average of a little over 5 parts per million. The average chloride content is equivalent to about 8.5 milligrams of common salt per liter of rain water. On the basis of the average annual rainfall for the city of Manila, these figures indicate a precipitation equivalent to about 165 kilograms of salt per hectare of land. It is of interest, though perhaps of no significance, to note that this figure is of the same order as that (120 kilograms) given by Prudhomme [133] as the salt requirement per hectare of coconut-palm plantations.

Rivers.—It is hardly necessary to point out that rivers vary greatly in flow under the influence of rain. Many streams that are almost dry in periods of drought become raging torrents during the rainy season. Under these circumstances, changes in quality are inevitable. However, in rivers that have consider-

[131] For the distribution of rainfall in the Philippines according to locality and season, cf. Cox, A. J., *Phil. Journ. Sci., Sec. A* (1911), 6, 287 ff.

[132] Most of these determinations were made by J. Gonzales Nuñez, chemist, Bureau of Science.

[133] Quoted by Beccari, O., *Phil. Journ. Sci., Sec. C* (1917), 12, 41.

able flow throughout the year such changes may be surprisingly slight. This is well illustrated by a series of measurements made on Mariquina River, the source of the Manila water supply. In 1903, when the intake was at Santolan, the tap water was examined over a period of months, including the rainy season, at very frequent intervals. The following maximum variations were noted: Total solids, 153 to 220; chlorides, 2.1 to 4.4; and oxygen consumed, 0.65 to 2.20.[134] Since the intake has been moved to Montalban, 10 or 12 kilometers upstream, a point above which there are no human habitations or cultivated lands, the fluctuations have been even less. Total solids have varied from 150 to about 200, usually being in the neighborhood of 160. A recent series of determinations,[135] during a period of frequent heavy rains, showed chloride contents varying from 3.5 to 4.1 and "oxygen consumed" varying from 0.67 to 1.4. Making due allowances for the effect of storage, changes of this magnitude in a water subject to tremendous fluctuations in quantity and even in appearance appear to be comparatively insignificant. It may be of interest to note, in this connection, that the temperature variation of Mariquina River water in the service reservoir was only 4° C. for an entire year.

Of far greater effect on quality is the influence of the tides. Many Philippine rivers show tidal ebbs and flows for many kilometers inland. Owing to the difference in specific gravity between fresh and ocean water, the latter apparently can move far inland in a river at high tide before it mixes with and contaminates the water of the stream. Thus samples taken from Pasig River about 1 kilometer from the sea showed the following analyses:

TABLE VI.—*Analyses of water from Pasig River.*

	Surface water.		Water taken near the bottom.	
	At high tide.	At low tide.	At high tide.	At low tide.
Turbidity	60	70	95	90
Alkalinity (as $CaCO_3$)	70	70	110	75
Total solids	760	780	31,000	8,000
Silica (SiO_2)	36	18	----------	69
Calcium (Ca)	17	2.8	820	100
Chlorides (Cl)	310	124	14,600	3,800
Sulphates (SO_4)	40	5.4	1,500	380

[134] Bliss, C. H., *Pub. P. I. Bur. Govt. Lab.* (1905), No. 20, 10.
[135] Heise, G. W., *Phil. Journ. Sci., Sec. A* (1916), 11, 4.

It may be mentioned that a tidal effect on the quality of Pasig River water has been noted for a distance of several kilometers upstream. The stream waters analyzed, with the exception of tidal rivers and water courses known to be contaminated, range from 45 to about 550 parts per million in total solids and from 2 to 150 in chlorine.

Surface wells.—Like rivers, surface wells show great changes in quantity of water with the season. Many that are capable of yielding much water in times of rain are absolutely dry during dry weather. The frequent influx of large quantities of surface run-off, after a heavy rain, may change materially the quality of water in a surface well. Quality of surface wells has not been much studied, except with regard to their potability. They are similar in composition to average river waters. Their waters show no marked peculiarities, and they have not been sufficiently studied to justify generalizations. The surface wells listed, with the exception of a few located so near the ocean that they were obviously contaminated by sea water, range in total solids content from 164 to 1,230 parts per million and in chlorine content from 5.5 to 436 (average, about 150).

Springs.—As might be expected, springs generally show great fluctuations in quantity under the influence of various factors. Most of them show a decidedly greater flow during the rainy season, even though they are protected from surface seepage. It is interesting to note that with deep-seated springs there is decided "lag," that is to say, a marked increase in flow does not occur until after a month or more of rainy weather, and furthermore, the increased flow does not materially diminish until far into the dry season.

Tidal variations are also of frequent occurrence, many springs having a much greater flow at the flood than at the ebb. This is to be expected, since the general effect of tides may frequently be an increase of the hydrostatic pressure of subsoil waters. In some cases the flow may entirely cease at low tide. A peculiar case in point has been already discussed.[136] A series of springs, some fresh, some brackish, are found on the seashore at Punta Oslob, Cebu, both above and below high-water mark. The fresh-water springs have no flow at low tide and are covered at high tide, but water can be obtained from them as it emerges into the supernatant sea water. As the only springs available at low tide are brackish, and as both fresh and salt springs are close together and are easily mistaken for one another, the

[136] Heise, G. W., *Phil. Journ. Sci., Sec. A* (1916), 11, 125.

erroneous belief has developed that the same springs are fresh at high tide and salt at low tide.

Spring waters vary widely in quality. The total solids content ranges from 24 to over 40,000 parts per million, and chlorides range from 0.7 to over 20,000. Many of the springs are so salty that ordinary salt can be recovered very profitably from them.

No such variations occur in quality as have been noted in quantity. Even the temperature appears to be surprisingly constant for long periods of time. Occasionally springs are reported as alternately hot and cold, but this observation, as was pointed out in the discussion of mineral waters, is generally unfounded. In regard to chemical quality, our records indicate that, except for seismic disturbances or other unusual factors, no material changes in quality occur, in spite of marked fluctuations in quantity. This constancy in composition of spring waters may be inferred from a comparison of two analyses of Sibul Springs, one published in 1890,[137] the other made in 1915.

TABLE VII.—*Analyses of Sibul Springs water.*

	Analysis by—	
	Centeno in 1890.[a]	Bureau of Science in 1915.[b]
Total solids	582	550
Silica	30	15
Bicarbonates (HCO_3)	477	460
Sulphates	13	nil
Chlorides	42	32
Calcium	154	150
Magnesium	17	14

[a] Recalculated as parts per million and to same terms as those used in standard practice.
[b] Analysis by F. Peña, chemist, Bureau of Science.

Considering the length of time that has elapsed between the two analyses, the differences in analytical methods employed, and the fact that for a period of years Sibul Springs was neglected, better agreement could be hardly expected.

Deep wells.—The fluctuations described for springs are also encountered in deep wells. Water is encountered at many different depths, depending on the locality in which well-drilling operations are carried on.[138]

[137] Centeno, J., et al., Memoria Descriptiva de los Manantiales, etc., de la Isla de Luzon. Madrid (1890), 39.

[138] For a discussion of the location of artesian wells, see the article by Pratt, reprinted as the first appendix of this work.

A large number of the wells drilled in the Islands have a natural flow, some of them supplying enormous quantities of water, notably, the famous gusher at Bayambang, Pangasinan, which supplies 1,000,000 gallons [3,800,000 liters] daily. The water from the latter is distributed through two main supply pipe lines, one leading to the military post at Camp Gregg, and the other to the town of Bayambang. In many of the provinces it is necessary to drill wells ranging from 600 to 800 feet [200 to 250 meters] in depth in order to obtain good water. In the town of Wright, Samar, good water was not encountered until a depth of 1,025 feet was reached, when flowing water of excellent quality was tapped. This well is the deepest in the Islands which supplies good water. A number of wells have been drilled to greater depths, however, but in every case except the one mentioned above salt water was encountered below 1,000 feet. The deepest well ever drilled in the Islands was located on the trade school grounds at Iloilo, and was sunk to a depth of 2,285 feet without encountering fresh water. An interesting feature in connection with some of the wells is the effect the ocean tide has upon the fresh-water flow, one remarkable instance being the well at Bauan, Batangas, drilled to a depth of 298 feet, which flows 250 gallons per minute 18 inches above the ground surface at high tide, and 50 gallons per minute at low tide at the same elevation; in other words, the flow at high tide indicates an increase of 400 per cent over the flow at low tide, notwithstanding the fact that analyses of water samples collected at both high and low tide give identical results and show the water to be potable and free from salt-water contamination.[139]

In many borings, especially near the coast, brackish water is encountered during the first 30 to 70 meters, even though fresh water may be found at lower levels. In some rather exceptional cases, in which salt water was encountered at great depths, continued drilling developed a supply of fresh water. At Wright, Samar, salt water was found at 180 to 215 meters; this was cased off, and drilling was continued. At 312 meters fresh water was found under sufficient pressure to cause a flow, which, although slight even at ground level, did not cease entirely at 12 meters above the earth's surface. As a general rule, however, it may be stated that fresh water is seldom found underlying salt water, and in the few cases in which such fresh water has been utilized, the well has frequently "gone bad" after more or less continued use.

Of interest in this connection is a phenomenon noted occasionally in the Philippines, especially on small islands. It has happened that water of fair quality has been encountered in deep wells; when the amount of water pumped was large, the waters have become too brackish for use, due, no doubt, to infiltration of sea water. On allowing the pumps to rest, or on decreasing the rate of pumping, fresh water has been again obtained.

[139] Vickers, J. W., *Quart. Bull. P. I. Bur. Pub. Works* (1914), 2, No. 4, 27. Many wells, for instance, at Iloilo and at Argao, Cebu, flow only at high tide.

The minimum temperature of deep wells drilled in the lowlands is about 28° C., but the temperature range is great.

The deep-well waters range in total solids content from about 120 (well 129, Nueva Caceres, Ambos Camarines) to 8,200 parts per million (Janiuay, Iloilo) and in chlorine content from 1.5 (San Jacinto and Binalonan, Pangasinan) to 4,471 (Janiuay, Iloilo).

The highest free ammonia content recorded is that of a well at Los Baños, Laguna, 70 meters deep, which showed 32.7 parts per million.

Except under very exceptional circumstances, such as those previously discussed, the chemical quality of a deep-well water remains practically unchanged for long periods of time. This observation is in harmony with the experience in other countries.[140] There is generally an appreciable variation in quality immediately after a well is drilled, but this appears to be due to a leaching-out of soluble ingredients from the neighboring soil and soon ceases. As was pointed out under the heading of the interpretation of analytical results, these variations often greatly impair the value of the available laboratory data and emphasize the necessity for allowing a well to reach equilibrium before its water is sent to the laboratory for analysis. Chemical quality, though generally not as subject to change as biological character, also undergoes marked alterations, so that interpretation of the analysis of old-water samples is sometimes very difficult. Free and albuminoid ammonia and, in general, nitrogen in its various forms will change greatly. The amount of free carbon dioxide originally present in a water diminishes comparatively rapidly on standing, particularly if the initial concentration is high. Many natural waters that are clear when they emerge from a well or spring quickly become turbid, owing to the escape of carbon dioxide and to the resulting precipitation of salts of metals (calcium, magnesium, and iron) previously held in solution in the form of bicarbonates. While the relations existing between free carbon dioxide, bicarbonates, and normal carbonates are not exactly understood, there is no doubt that the escape of carbon dioxide affects the equilibrium of the system. It has been observed in this laboratory that samples of water kept for a considerable period of time rapidly lost their

[140] Hintz, E., and Kaiser, E., *Zeitschr. f. prakt. Geol.* (1915), 23, 122–126, through *Chem. Abst.* (1916), 10, 1741, state that the composition of deep-seated waters from wells is remarkably constant.

"acidity" due to free carbon dioxide. As long as an appreciable excess of free carbon dioxide was present, the bicarbonate value remained constant, but as soon as the free carbon dioxide reached a limiting concentration—in this case, zero—normal carbonates began to form at the expense of the bicarbonates, which suffered a corresponding reduction of concentration. Other changes, such as the precipitation of suspended matter and variations in color, odor, and taste, may also occur.

Such variations often lead to erroneous interpretations of water analyses, a fact which will be discussed more at length.

METHODS OF WATER EXAMINATION

The usual difficulties encountered in laboratories devoted to water-supply problems are, on the whole, greatly increased in the Philippines. Chief among these has been the difficulty in getting representative samples in proper condition for analysis to the Bureau of Science, in Manila, which is the central laboratory for the Archipelago and is the only laboratory properly equipped to do water analyses. Many samples have to be transported hundreds of kilometers before they can be analyzed. Since much of the transportation is by water, samples are often three or four weeks old when they reach the Bureau of Science. With the exception of those taken in Manila and at points easily accessible to it by railroad, samples rarely reach the Bureau within the time limits prescribed by the American Public Health Association.[141] The uniform, high temperature in the Philippines accelerates the changes that normally occur in bottled waters and greatly increases the importance of the time factor. It is not surprising, therefore, that many samples, when they do arrive at the laboratory, are not representative.

Another handicap to constructive work in the Philippines has been the difficulty in securing properly taken samples. For many years the Bureau of Science has sent out properly packed, sterile, glass-stoppered bottles, suitable for water and has issued instructions for the collection of samples. The directions of the Bureau of Science for taking water samples, as prepared for general distribution, are shown in the appendix. However, the primitive conditions in many isolated districts have resulted in improperly taken samples, usually in unsuitable and frequently in unclean containers, accompanied by little or no information that would assist in the proper interpretation of the results obtained from an analysis or would make such analysis of permanent value.

In addition, there is a peculiar difficulty, for which general conditions, rather than individuals, are to blame. As has been mentioned, judgment by the Bureau of Science must be made on all artesian wells drilled by the Insular Government. The

[141] Standard Methods for the Examination of Water and Sewage (1915), 1–2.

great cost of well-drilling apparatus and the constant demand for new wells make it impracticable to keep machinery and crew idle for any length of time. Accordingly, when a well-driller strikes water that he believes to be potable, he takes a sample and forwards it to the Bureau of Science for analysis.

It frequently happens that the first water from a well is not a representative sample of that well under working conditions, so that the analysis is of doubtful value as a matter of permanent record. It has been our experience that a new well, or one that has been in disuse for any protracted period of time, should be given a thorough pumping test before a sample of the water is taken for analysis.

The general methods employed in the examination of water are three, namely, a sanitary survey, a microscopic and biological examination, and a chemical analysis. The sanitary survey consists of a study of the surroundings of a source and gives information concerning the possible sources of contamination; the chemical analysis, as the name implies, is a determination of the composition of the foreign ingredients suspended or dissolved in water; the biological examination is a differentiation in kind and frequently in quantity of the smaller floating organisms, both animal and vegetable (technically known as plankton), usually found in natural waters. These general methods, together with a discussion of the interpretation of the results of a water examination, will be taken up in the order named.

SANITARY SURVEY

The sanitary survey legitimately includes all external factors that might have influenced the quality of the water when the sample was taken and might affect the quality in the future. These factors, of course, vary to some extent, in every case. In addition to general information on the quantity and apparent quality of the water, possible sources of contamination, etc., the following data should be noted:

Wells:

A. Artesian. Depth of well; depth of casing; head; capacity; variations; distance from nearest houses. If pumping well, kind and condition of pumps; nature of soil and subsoil; drainage of waste water, etc.

B. Surface. Depth of well; kind and depth of casing; height of curbing; nature of covering; nature of receptacles used for drawing water; distance from habitations; kind of pump, if any; nature of soil and subsoil; elevation with respect to surroundings; drainage of waste water; density of population, possible sources of contamination, etc.

Springs. Water-bearing stratum; apparent direction of flow; elevation; liability to contamination with surface water; distance from houses; density of population; nature of soil; variations, etc.

Rivers. Nearness and relative number of houses along course; nature and slope of valley; variations, etc.

It is also important to note the weather conditions at the time the sample is taken. This applies particularly during periods of heavy rains or long droughts.

In all cases, the location of the source should be stated as fully and accurately as possible, to prevent the slightest possibility of confusion with any other point in the vicinity.

Local opinion is obviously of great importance. Prejudice and preconceived ideas have in numerous cases led to the unjust condemnation of good water and the unwarranted approval of bad.

In connection with the field examination of potable waters, the general hygienic and sanitary conditions in the neighborhood of the source should, of course, be noted. In addition, information should be obtained as to the prevalent diseases and to the occurrence of epidemics.

BIOLOGICAL EXAMINATION

Both laboratory and field methods are used in making biological examinations of water. The laboratory tests are made in the Bureau of Science by the biological laboratory, and the field work is done by chemists of the division of general, inorganic, and physical chemistry.

LABORATORY METHODS

The usual laboratory procedure includes 24- and 48-hour colony counts, a presumptive test for *B. coli* or related organisms, and an examination for the commoner protozoa. The routine methods of bacteriological examination employed in the biological laboratory of the Bureau of Science are as follows:

1. Agar plates are poured with 1 cubic centimeter, 0.1 cubic centimeter, and 0.05 cubic centimeter of water, counts being made at the end of twenty-four and forty-eight hours. The reported number of colonies is the mean of the two serial counts (a total of six individual counts).

2. Five fermentation tubes containing not less than 30 cubic centimeters of lactose peptone broth or bile are inoculated with 10 cubic centimeters of the water under examination, incubated for forty-eight hours at 37°C., and then observed for gas formation (presumptive test for *B. coli* group).

3. From each tube showing gas, litmus lactose or Endo plates are made and observed for red colonies at the end of twenty-four and forty-eight hours' incubation (isolation of organism of colon group).

Special methods are, of course, employed when necessary for the isolation and differentiation of uncommon organisms.

FIELD METHODS

The bacteriological examination in the field consists of two parts. One of these is a colony count, made from two plate cultures. The other is a presumptive test for the presence of organisms of the *B. coli* group, made with one or more culture tubes.

The culture medium used in both cases is litmus lactose agar (1.5 to 2.0 per cent agar, 1 per cent lactose). The reaction of this medium is almost neutral, there being present barely enough alkalinity to give a slight blue color. It is put up in test tubes, in 10 cubic centimeter portions, and is thoroughly sterilized.

The Petri dishes used for the plate cultures are packed into individual envelopes and then sterilized. The envelopes, made of heavy Manila paper, are about the same width as the dishes and about twice as long as they are wide. Packages of six plates, well wrapped with paper, may be transported with little danger of breakage and will remain sterile indefinitely.

The pipettes used hold 1 cubic centimeter and are about 20 centimeters long. If these are not available, they may be readily made from glass tubing. The pipettes in lots of six are well wrapped in cheesecloth, having several folds of cloth between one pipette and the next. The ends of the package are tied together, and the package is inserted in a tin can just large enough for the purpose. The closed tin can containing the pipettes is then sterilized. While warm, the can is sealed with adhesive tape. When cool, the tape is well covered with paraffin. Pipettes so packed will remain sterile almost indefinitely.

For several kinds of work sterile bottles may be employed. Instead of the ordinary cotton plugs, which are often either pushed in or which come out during transportation, we use a cotton-covered cork. This arrangement has been found to be very satisfactory.

Ordinarily two plate cultures and one tube culture are made of every sample. Three tubes of media are thus required. The tubes are melted by heating in water over an alcohol lamp, then cooled to 45°.

Plating is done at a temperature of 40 to 43° C. For a water, such as that from a spring or artesian well believed to be comparatively pure, 0.5 and 1.0 cubic centimeter cultures are made. For a water suspected of contamination, plates may be made of 0.2, 0.1, or 0.05 cubic centimeter, depending on the apparent

degree of contamination. The water is introduced into the Petri dish, the liquefied agar added, and the plate manipulated to insure thorough mixing. After thorough cooling, the plates are returned to their envelopes and carried in an inverted position to prevent spreading of the colonies by water of condensation.

The tube culture for the presumptive test is made by introducing the desired amount of water into the tube of liquefied agar and mixing thoroughly by agitation. Usually 1 cubic centimeter is taken for this test, though more or less may be employed. The upper limit will be determined by the fact that 1 per cent agar is the weakest that will solidify on cooling to the temperatures ordinarily encountered (25° to 30° C.).

Incubation is at the ordinary temperature. No special apparatus is, therefore, required.

Colony counts are made both at the end of twenty-four and forty-eight hours, using a lens magnifying at least five diameters. The average of the two counts is the recorded value.

When the number of colonies is high, the plate is marked into sectors of convenient size, and the total number of colonies is estimated, or else the number on representative areas of 1 square centimeter is determined (a small card with openings of appropriate size and shape has been found very convenient for field work), and the necessary calculation for the total area is made. The presence of red colonies is noted.

The presence of organisms of the colon group is indicated by the formation of gas in the tube cultures and by the formation of acid, as shown by the change of litmus from blue to red.

Bacteriological methods are, in general, notably inexact, although the data thus secured are of the greatest value. Furthermore the results obtained are subject to a wide range of interpretation. For these reasons a discussion of the probable error involved in the field methods of bacteriological examination is scarcely necessary. The interpretation of the data thus secured, however, will be dealt with in the following chapter.

CHEMICAL ANALYSIS

Both laboratory and field examinations of water are made by the Bureau of Science. As the methods used differ considerably in the two instances, they will be discussed separately.

LABORATORY METHODS

The methods of chemical analysis employed in the Bureau of Science laboratory are, in general, the standard methods of the American Public Health Association. A few changes and omis-

sions have been made. The most important of these is with regard to the determination of nitrogen in the form of nitrates, nitrites, and free and albuminoid ammonia. None of these determinations is now made in a routine mineral analysis and only in special cases in a sanitary analysis of a water.

The status of nitrogen determination has entirely changed during the last few years. As Barnard [142] has pointed out, streams loaded with sewage are often surprisingly low in nitrates. Nitrates show greater variation due to high or low water than to sewage or oxidation of nitrogenous material. Free and albuminoid ammonia generally depend more on low and high water, temperature, and normal vegetable growth than upon pollution. Furthermore, since the nitrogen content of deep wells is almost sure to be misleading, since single determinations are of doubtful value, and since the nitrogen in its various forms can be determined accurately only on fresh samples of water, the nitrates, nitrites, and free and albuminoid ammonia determinations may be omitted for all but exceptional cases.

Similarly the determination of "oxygen-consuming power" is very seldom made when only single analyses are required. It has been repeatedly shown that this determination does not measure accurately the amount of organic matter in a water, that the values obtained vary widely with the method used, and that numerous errors may be introduced by the irregular behavior of many dissolved substances.[143] This determination is valuable chiefly as a sensitive indicator of fluctuations in a water supply kept under constant control. When a single analysis only is made, the results obtained for the oxygen-consuming power are of questionable value.

In this laboratory the determination of oxygen consumption by digestion at room temperature with alkaline permanganate solution [144] is preferred to the standard procedure [145] of the American Public Health Association, namely, 30-minute digestion at boiling temperature with acid permanganate solu-

[142] *Eng. Record* (1913), **68**, 291.

[143] For a discussion of the factors influencing the determination of oxygen-consuming power, cf. Standard Methods for the Examination of Water and Sewage (1915), 26–30; also Heise, G. W., and Aguilar, R. H., The oxygen-consuming power of natural waters, *Phil. Journ. Sci., Sec. A* (1915), **11**, 37–47.

[144] Method of Schultze, *Dingler's polytech. Journ.* (1868), **188**, 197, as modified by Winkler, L. W., *Zeitschr. f. analyt. Chem.* (1914), **53**, 561.

[145] Standard Methods for the Examination of Water and Sewage (1915), 29.

tion. The directions for the method of procedure followed in this laboratory are as follows:

Put 100 cubic centimeter samples of water into scrupulously clean bottles, add 10 cubic centimeters of (0.01 *N*) permanganate solution (containing 20 grams of sodium hydroxide per liter), and allow the samples to digest for twenty-four hours at room temperature. Acidify with 10 cubic centimeters of dilute sulphuric acid (10 per cent), allow to stand for one or two minutes, and add 2 cubic centimeters of 10 per cent potassium iodide solution. Titrate the liberated iodine as quickly as possible with 0.02 *N* sodium thiosulphate solution. The solution must be acidified before the potassium iodide is added, else nitrites will not be oxidized and concordant titrations will not be obtained.

This method greatly reduces, but does not eliminate, the error due to the presence of chloride, so that, when the chloride content is large (approximately 150 parts per million or over) it is best to shake a water sample with silver oxide, to remove chlorides [146] before proceding with an analysis.

Total hardness has been usually determined by calculation from the gravimetric determinations of calcium and magnesium and reported in terms of calcium carbonate. Recently the Blacher method [147] for the determination of total hardness by titration with a solution of potassium palmitate has been studied, and this method, in slightly modified form, is now included among the standard methods employed in this laboratory.[148]

The only other deviation from the standard methods worthy of mention has been the substitution of dimethylaminoazobenzene (butter yellow) in place of lacmoid, methyl orange, and erythrosin in the determination of alkalinity. Recent work indicates that the first-named indicator gives the most reliable results, the end point being almost independent of carbon dioxide.[149]

The following determinations are made in a routine water analysis as carried out in this laboratory: Color, turbidity, alkalinity, acidity, total solids, silica, iron and aluminium oxides, iron, aluminium, calcium, magnesium, chlorides, normal carbonates, bicarbonates, sulphates, and total hardness.

[146] Sachs, J. H., *Journ. Ind. Eng. Chem.* (1916), 8, 406.

[147] Blacher, G., Grünberg. P., and Kissa, M., *Chem. Zeitschr.* (1913), 37, 568.

[148] Behrman, A. S., Note on the Blacher method for the determination of hardness in water, *Phil. Journ. Sci., Sec. A* (1916), 11, 291.

[149] Norton, J. F., and Knowles, H., *Journ. Am. Chem. Soc.* (1916), 38, 877.

Results are reported in terms of parts per million and in numerical values of two significant figures (except in the case of *5* in the place of the third significant figure, which is so reported). This method of reporting in terms of two significant

BUREAU OF SCIENCE
WATER
CHEMICAL ANALYSIS
[Results expressed as parts per million.]

Laboratory No
Physical characteristics
Color
Odor
Turbidity (as SiO_2)
Alkalinity (as $CaCO_3$)
Acidity (as CO_2)
Total solids
Fixed solids
Loss on ignition
Appearance on ignition
Silica (SiO_2)
Iron & aluminium oxides ($Fe_2O_3+Al_2O_3$)
Iron (Fe)
Aluminium (Al)
Calcium (Ca)
Magnesium (Mg)
Sodium (Na)
Potassium (K)

Date , 191
Chlorides (Cl)
Normal carbonates (as CO_3)
Bicarbonates (as CO_3)
Sulphates (SO_4)
Nitrates (NO_3)
Nitrites (NO_2)
Free ammonia
Albuminoid ammonia
Oxygen consumed
Total hardness (as $CaCO_3$)
Temporary hardness
Permanent hardness
Estimated encrustants
Classification for boiler use
Remarks

Analyst.

BIOLOGICAL EXAMINATION

Date
Colonies per cc. 24 hrs ; *48 hrs* *Presumptive test*
Protozoa *Attempt to isolate B. coli*
Remarks
2—47

Bacteriologist.

B. Sc. Form No. 41.

BUREAU OF SCIENCE
MANILA, P. I.
WATER

Laboratory No
Location (Province.) (Town.) (Barrio.)
Source
Type
When installed
Capacity per minute:
Flows
Pumps
Quality of water
Effect of pumping
Temperature
Owner
Depth of well
Depth of casing
Diameter
Head above (+) *or below* (−) *surface*
Variations
Water-bearing stratum
Local opinion
Nature of examination
2—47

Day and hour of collection , 191
Report on sanitary survey
Sample collected by
Analysis requested by

FIG. 1. The two sides of one card. The top of the obverse is the bottom of the reverse.

figures is now generally accepted[150] as being consistent with the errors involved in determination. Any unusual physical characteristics such as taste and odor, not measurable quantitatively, are recorded.

[150] Standard Methods for the Examination of Water and Sewage (1915), 14.

FIELD ASSAY

Recent developments in water analysis have emphasized the importance of making examinations at the source, whenever possible. The work of the Bureau of Science has shown, as indicated in a previous chapter, the need of field investigations and the peculiar applicability of field methods to Philippine conditions. Accordingly field work has been made one of the most important features of our study of water supplies.

Owing to the comparative isolation of the Philippines, the great distance from scientific or manufacturing centers, and the consequent loss of time when apparatus and supplies are procured from abroad, we have found it necessary, to a large extent, to build our own apparatus, to prepare our own reagents for field use, and to devise and adapt methods suitable to our needs.

The field work of the Bureau of Science has been now carried on for three years. Because of the importance of field methods at the present time and because workers in the Philippines will continue to be dependent, in a great measure, on their own resources, we thought it advisable to describe our field methods and apparatus in detail.

Our methods are based upon those described by Leighton.[151] However, several changes have been made. A "tabloid" determination of acidity and a rough estimate of the total amount of solid matter have been added; the soap method for total hardness has been replaced by a new and more accurate procedure; and several minor modifications in the details of manipulation of some of the old methods have been introduced. Other minor changes have been made in apparatus, as will become evident in the detailed description to follow.

In connection with the study of potable waters, a field bacteriological examination is also made. This consists of 24- and 48-hour colony counts at ordinary temperature and a presumptive test for *B. coli* or related organisms that would indicate fæcal contamination. The uniform tropical temperature (25 to 30° C.) makes this bacteriological work a very simple, while a very valuable, feature of the examination.

The outfit has been gradually reduced in size, although the number of determinations made has been increased, so that now enough apparatus and materials for a month's chemical work can be carried in an army telescope. This makes a package weighing less than 22 kilograms, which fits well on one side

[151] Leighton, M. O., Field assay of water, *U. S. Geol. Surv., Water Supply Paper* (1905), No. 151.

of a packsaddle or on the back of a cargador. The outfit required for bacteriological work is not large, as may be seen by Plate XIX, in which the complete equipment is shown.

A comprehensive sanitary survey, embracing, in so far as possible, all those features that may influence the quality of the water under examination is, of course, included in field work.

The details of the methods employed in regular field examination are as follows. Quantitative: Color; turbidity (as SiO_2); alkalinity (as $CaCO_3$); acidity (as CO_2); iron (Fe); chlorides (Cl); normal carbonates (as Na_2CO_3); bicarbonates (as $CaCO_3$ or HCO_3) by calculation; sulphates (as SO_3); total hardness (as $CaCO_3$); estimated encrustants, by calculation. Qualitative: Odor; total solids; appearance on ignition; calcium; classification for boiler use.

Color is determined with the United States Geological Survey color outfit described by Leighton,[152] consisting of a standard length aluminium tube that is filled with the water under examination. The color of this column of water, viewed longitudinally, is matched by disks of colored glass that have been rated in parts per million to correspond to the platinum-cobalt standard.

Iron is conveniently determined with the same outfit as used for color as described by Leighton. The only extra equipment required is a series of prepared colored disks corresponding to those by treating standard solution of iron. These disks have not been available. In lieu thereof, red and yellow glasses from the Lovibond tintometer have been employed in connection with two matched Nessler tubes in galvanized iron outer tubes. When 100 cubic centimeters of water were used in a determination, it was found that a summation of 6.0 on the Lovibond scale was very nearly equal to 1 part per million of iron (as Fe). The following is the procedure employed:

To 100 cubic centimeters of the water under examination in a Nessler tube add 4 cubic centimeters of concentrated nitric acid. Mix thoroughly by pouring six or seven times from one tube to another and allow to stand at least five minutes to insure complete oxidation. Then add 6 cubic centimeters of a 2 per cent solution of potassium sulphocyanide, mix thoroughly by several pourings, and allow to stand ten minutes for the color to develop. Exactly at the end of ten minutes make the color comparison with the Lovibond glasses under the empty Nessler tube, using a piece of white paper to reflect the light. Hold the tubes with one hand sufficiently high to reflect all the light

[152] Loc. cit.

possible. Interchange the tubes several times to avoid inequalities of light. The tubes should be held in such a position that both may be seen with one eye. Obviously the final reading may be made either by using all the glasses under the empty Nessler tube or with some under the water as well. In this way intermediate values sometimes not otherwise obtainable may be found. In all cases the nitric acid used should be tested beforehand for iron, this being a not infrequent impurity.

Turbidity is determined with an electric turbidimeter, described in Leighton's paper. By means of an electric flash light, a cross of light is provided at the bottom of a long graduate tube. The well-shaken, turbid water is poured in until the sharp image disappears and the hazy cross of light just disappears. This is taken as the end point in the lower part of the tube. In the upper part of the tube (that is, for slightly turbid liquids) there is no hazy cross of light, and the end point is taken as the depth at which the sharp image of the cross disappears, giving place to a slightly blurred one, that is, it seems out of focus. Table VIII is provided for converting the turbidimeter depths to parts per million silica.

TABLE VIII.—*For converting readings in depths by the turbidimeter into parts per million of sulphate.*

Reading.	Parts per million SO_3.	Reading.	Parts per million SO_3.	Reading.	Parts per million SO_3.	Reading.	Parts per million SO_3.	Reading.	Parts per million SO_3.	Reading.	Parts per million SO_3.
cm.		*cm.*		*cm.*		*cm.*		*cm.*		*cm.*	
1.0	522	3.2	173	5.4	104	7.6	75	10.8	53	19.0	30
1.1	478	3.3	168	5.5	103	7.7	74	11.0	52	20.0	29
1.2	442	3.4	164	5.6	101	7.8	73	11.2	51	21.0	28
1.3	410	3.5	159	5.7	99	7.9	72	11.4	50	22.0	27
1.4	383	3.6	155	5.8	97	8.0	71	11.6	49	22.5	26
1.5	359	3.7	151	5.9	96	8.1	70	11.8	48	23.0	25
1.6	338	3.8	147	6.0	94	8.2	69	12.0	47	24.0	24
1.7	319	3.9	144	6.1	93	8.3	68	12.4	46	25.0	23
1.8	302	4.0	140	6.2	91	8.5	67	12.6	45	26.5	22
1.9	287	4.1	137	6.3	90	8.6	66	12.8	44	28.0	21
2.0	273	4.2	133	6.4	88	8.7	65	13.0	43	29.0	20
2.1	261	4.3	131	6.5	87	8.8	64	13.5	42	31.0	19
2.2	250	4.4	128	6.6	86	9.0	63	14.0	41	33.0	18
2.3	239	4.5	125	6.7	84	9.1	62	14.5	39	35.0	17
2.4	230	4.6	122	6.8	83	9.3	61	15.0	38	37.5	16
2.5	221	4.7	119	6.9	82	9.5	60	15.5	37	40.0	15
2.6	213	4.8	117	7.0	81	9.7	59	16.0	36	43.0	14
2.7	205	4.9	115	7.1	80	9.8	58	16.5	35	46.5	13
2.8	198	5.0	113	7.2	79	10.0	57	17.0	34	50.0	12
2.9	191	5.1	110	7.3	78	10.2	56	17.5	33	55.5	11
3.0	185	5.2	108	7.4	77	10.4	55	18.0	32	62.0	10
3.1	179	5.3	106	7.5	76	10.6	54	18.5	31	68.0	9

Turbidity may be also determined with the turbidity rod, which consists merely of a bright platinum wire fastened at right angles to a tape. Under the proper conditions the tape is lowered into the water under examination, and the end point is taken as the depth at which the wire just disappears from view. The tape is calibrated directly to read parts per million silica.

The disadvantage of the turbidity-rod method is the required nicety of adjustment of conditions, involving the use of a large sample under circumstances often impossible. The turbidimeter method, on the contrary, is independent of most of these conditions. Only a small sample is required. Since the method is based on the diffraction of light, the accuracy of the determination is almost independent of the intensity of the light and, therefore, of the condition of the batteries and bulb. It follows directly that the original calibration as given by Leighton is applicable to any well-constructed turbidimeter. No difficulty was experienced in having a suitable instrument constructed for our purposes.

Sulphates are also determined with the turbidimeter, as described by Leighton. To 100 cubic centimeters of the water are added 1 cubic centimeter of HCl (50 per cent concentrated acid by volume) and 1 gram of powdered crystals of solid barium chloride. Precipitations are conveniently made in 250 cubic centimeter glass-stoppered bottles. The water is allowed to stand for ten minutes, with frequent shakings. The turbidity produced is then determined with the turbidimeter as before. The sulphate content (as parts per million of SO_3) is read from the table of turbidimeter depths.

Calcium was formerly determined turbidimetrically by the United States Geological Survey method, but this has been abandoned because of its inaccuracy.

The qualitative field test for calcium is made by adding enough ammonia to some of the water in a test tube or bottle to make it alkaline to litmus and then adding some ammonium oxalate.

Total solids are determined qualitatively by evaporating 50 cubic centimeters of the water in a porcelain casserole to dryness over an alcohol lamp. The solid content is reported merely as "very small," "moderate," "large," etc. The residue is then ignited, and any change in "appearance on ignition" is noted. This may be a browning or blackening due to organic matter or a deep red-brown coloration due to the oxidation of considerable amounts of iron present. The last is of value as a confirmatory test for large amounts of iron.

152918——8

Odor is reported, wherever possible, in such a way that both the derivation and the relative amount are indicated, namely, "very slightly sulphuretted," "strongly acid," etc.

Alkalinity, acidity, chlorides, normal carbonates, and total hardness are determined by the use of tablets, as outlined by Leighton. In brief, this method consists of the use of pellets containing known amounts of reagents, instead of standard solutions. The titrations are performed in a small (100 to 150 cubic centimeters), heavily glazed porcelain mortar, a pestle being used to crush the pellets and to stir the liquid. The volume of water used for a titration is conveniently measured from a tall 100 cubic centimeter graduated cylinder, provided with a double scale, so that both the water withdrawn and the volume remaining can be directly read. What are practically duplicate determinations can be made very rapidly in the following manner: A few pellets are crushed in the mortar, and water is added from the cylinder till the end point is reached. The volume used is noted. Several more pellets—preferably the same number as before—are added, followed by water from the cylinder until the second end point is obtained. In this way not only is it possible to secure more accurate results by taking the mean of the two values obtained than by making a single determination, but in addition, any gross error that may arise from an unclean mortar, contaminated indicator, or defective tablet can be detected and corrected.

The following reagents are used in tablets in the various determinations:

Sodium acid sulphate for alkalinity and normal carbonates; sodium carbonate for acidity; silver nitrate for chlorides; and potassium palmitate for total hardness.

Kaolin is used as the filler and binding material for the sodium carbonate and silver nitrate pellets, while glucose is employed for those of sodium acid sulphate and potassium palmitate. Glucose is superior to kaolin, as it is completely soluble and consequently does not obscure the end point. It cannot, however, be used in the first two cases, because unstable pellets result. Water is used in all cases in making up the pill mass. The reagent is dissolved in water and carefully stirred into the binding material. The mass is kneaded in a mortar, more water being added if necessary, until it is homogeneous and of the desired consistency.

The tablets are made in a tablet mold. We use a hard rubber mold (No. 10, Whitall Tatum Co., for making 50 one-grain tablets at a time). The molded pellets are dusted with pow-

dered talc, dried in the air and then in a desiccator over calcium chloride, after which they are packed in glass tubes about 15 centimeters in length holding about forty pellets each. The tubes are sealed with paraffin, and those containing pellets of silver nitrate are covered with heavy black paper. Needless to say, the silver nitrate pellets are made in a dark room.

The silver nitrate and sodium carbonate pellets retain their strength almost indefinitely without change. Those of sodium acid sulphate lose strength very slowly and should be restandardized every month. The potassium palmitate pellets lose strength rather rapidly and should be restandardized weekly.

For the determination of alkalinity, pellets are molded from a pill mass containing 6.5 grams of crystallized sodium bisulphate and 150 grams of glucose, the proportions that will yield a pill of very nearly the desired strength (one pellet equivalent to 1 milligram $CaCO_3$). The pellets are standardized by crushing five of them in a mortar with a little distilled water and adding a drop of butter-yellow indicator solution (0.2 gram butter yellow in 100 cubic centimeters of alcohol). Tenth-normal sodium hydroxide or sodium carbonate is added till the end point is reached. From this titration the reacting value of the pellets may be readily calculated.

The field determination of alkalinity is analogous to the standardization of the pellets. The 100 cubic centimeter cylinder is filled to the mark with the water under examination. Two or three of the pellets are crushed in the mortar with a little of the water, and a drop of the indicator is added, followed by more water from the cylinder till the end point is reached. The volume of water used in the titration is noted, readings being taken to the tenth of a cubic centimeter. Two or three more pellets are added, followed by more of the water to the second end point.

The alkalinity, expressed as parts per million calcium carbonate, is readily calculated from the number and strength of pellets and the volume of water used in the determination. Thus, if 4 pellets of sodium bisulphate, each equivalent to 1.10 milligrams of calcium carbonate, require 22.4 cubic centimeters of the water for interaction, the alkalinity will be

$$\frac{1{,}000 \times 4 \times 1.10}{22.4} = 196$$

and would be reported as 200 (that is, in terms of two significant figures).

If normal carbonates (or hydroxides) are present, the water

will give a pink coloration with phenolphthalein. In this event the amount of normal carbonates is determined with pellets of sodium bisulphate. The procedure is identical with that for the determination of alkalinity, except that five drops of phenolphthalein indicator solution (1 per cent alcoholic) are used instead of the one drop of butter yellow. Where the normal carbonates are present only in small amount, half, or even a quarter, of a pellet may be all that can be used.

As phenolphthalein is sensitive to carbonic acid, the end point in this determination is reached when only half of the alkali is neutralized. Accordingly the same sodium bisulphate pellet that was equivalent to 1.10 milligrams of calcium carbonate in the determination of alkalinity will be equivalent to twice that amount, or 2.20 milligrams, when used in the determination of normal carbonates.

Thus if 2 of these pellets require 57 cubic centimeters of the water for the reaction, the results, expressed in parts per million of calcium carbonate, would be

$$\frac{1{,}000 \times 2 \times 2.20}{57} = 77.$$

When, as is usually the case with Philippine waters, the phenolphthalein alkalinity is less than half that determined with butter yellow, the alkalinity of a natural water is caused by bicarbonates and normal carbonates and is equal to their sum. If, therefore, no normal carbonates are present, the alkalinity is numerically equal to the bicarbonates, when both are expressed in terms of calcium carbonate. If, when normal carbonates are present, the alkalinity is found to be equal to the normal carbonates—that is, when the phenolphthalein titration is one-half that with butter yellow—the absence of bicarbonates is indicated. If the alkalinity is found greater than the normal carbonates, the difference will be the bicarbonates, all expressed as calcium carbonate.

If, however, the phenolphthalein titration is more than one-half that with butter yellow, waters contain calcium or other alkaline hydrates (caustic alkalinity). In this case the phenolphthalein alkalinity subtracted from the butter-yellow alkalinity is equal to one-half the normal carbonate alkalinity. The caustic alkalinity is the difference between the normal carbonate and the total alkalinity. In case the phenolphthalein and butter-yellow titrations are identical, all of the alkalinity is due to hydrates.

The relations between the various forms of alkalinity just discussed are shown in Table IX.[153]

TABLE IX.—*Relation between normal carbonates, bicarbonates, and hydrates in natural waters, as indicated by titration with sulphuric acid (sodium bisulphate) in the cold.*

	Carbonates.	Bicarbonates.	Hydrates.
P=0	0	B	0
P<½ B	2 P	B-2P	0
P=½ B	2 P	0	0
P>½ B	2 (B-P)	0	2P-B
P=B	0	0	B

P = Phenolphthalein titration. B = Butter-yellow titration.

TABLE X.—*Conversion of turbidimeter readings in centimeters to parts per million of turbidity.*

Reading.	Turbidity as SiO_2.	Reading.	Turbidity as SiO_2.	Reading.	Turbidity as SiO_2.	Reading.	Turbidity as SiO_2.
cm.	*Parts per million.*	*cm.*	*Parts per million.*	*cm.*	*Parts per million.*	*cm.*	*Parts per million.*
2.3	1,000	6.3	350	10.5	210	19.6	110
2.6	900	7.3	300	11.0	200	21.7	100
2.9	800	7.6	290	11.5	190	23.0	90
3.2	700	7.8	280	12.1	180	25.0	80
3.5	650	8.1	270	12.8	170	28.0	70
3.8	600	8.5	260	13.6	160	31.0	60
4.1	550	8.7	250	14.4	150	35.0	50
4.5	500	9.1	240	15.4	140	42.0	40
4.9	450	9.5	230	16.6	130	52.0	30
5.6	400	10.0	220	18.0	120	70.0	20

When it is desired to express normal carbonates as sodium carbonate, the calcium carbonate value is multiplied by 1.06. Similarly the bicarbonates may be converted to the bicarbonate radical by multiplying the calcium carbonate equivalent by 1.22.

If a water reacts acid to phenolphthalein, the presence of carbonic or a mineral acid is indicated. In the first case bicarbonates may be present, but normal carbonates will not. In the second case, neither bicarbonates nor normal carbonates can be present, and the water will react acid to butter yellow or methyl orange as well as to phenolphthalein.

Mineral acidity, when present, is determined with pellets of sodium carbonate, using butter yellow as an indicator. Total acidity, due to the combined effect of mineral and carbonic acids, is also determined with pellets of sodium carbonate, but

[153] Cf. Standard Methods of Water Analysis, p. 39.

in the presence of phenolphthalein as indicator. The carbonic acid acidity is the difference between the total and the mineral acidities.

Mineral acidity in natural waters is rarely encountered in the Philippines. Acidity is practically always due to free carbon dioxide and is, therefore, determined with sodium carbonate pellets, using 5 to 10 drops of phenolphthalein solution as indicator. The manipulation is identical with that described for "alkalinity" and "normal carbonates," except that, ordinarily, only one or two tablets, or even less, will be required for a titration. Furthermore, since the kaolin in the pellets slightly obscures the end point, the discrepancy between duplicate determinations is usually 0.5 cubic centimeter and often 1 cubic centimeter.

In the manufacture of the sodium carbonate pellets 4 grams of anhydrous sodium carbonate are used to 130 grams of kaolin. This gives a pellet of approximately the desired reacting value, namely, 1 milligram of carbon dioxide. To standardize, 5 of these pellets are triturated in a mortar with recently boiled distilled water, 5 drops of phenolphthalein solution are added, and the solution is titrated with 0.1 *N* sulphuric acid.

If, in a field determination, it is found that 24 cubic centimeters of the water is the average of two readings taken for the reaction with one pellet equivalent to 0.95 milligram of carbon dioxide (phenolphthalein being used as indicator), the acidity, expressed in parts per million of carbon dioxide, would equal $\frac{100 \times 0.95}{24} = 40$.

For the determination of chlorides, "weak" and "strong" pellets of silver nitrate are employed. The former are each equivalent to about 1 milligram of chlorine, the latter to 10 milligrams. In the manufacture of the weak pellets, 12.5 grams of silver nitrate and 200 grams of kaolin are used, while 156 grams of silver nitrate and 250 grams of kaolin are the proportions used for the strong pellets.

The pellets are standardized with a sodium chloride solution, which is conveniently made to be equivalent to 1 milligram of chlorine per cubic centimeter. Potassium chromate is used as an indicator.

The determination of chlorides in the field is rapid and simple. A small quantity of water, usually only 10 or 15 cubic centimeters, is introduced from the filled 100 cubic centimeter graduate into the mortar, and 5 drops of potassium chromate solution (5 per cent) are added as indicator. If the chlorine

content of the water is high, "strong" silver nitrate pellets are added one at a time, with thorough mixing, until an excess is indicated by the rose color of silver chromate. If the chlorine content is low, "weak" pellets are added until the end point is passed. If the chlorine content is low, that is, under 10 parts per million, a half or even quarter tablet will be sufficient. In any case, after an excess of silver nitrate has been provided, more water is added from the cylinder until the rose color is entirely displaced by a bright yellow, corresponding to the shade used in standardization. Check determinations may be made as before by adding more pellets and titrating.

If, to react with a half of a "weak" tablet (a whole tablet being equivalent to 0.96 milligram Cl), there were required 76 cubic centimeters of the water under examination, the chlorine content, expressed in parts per million of chlorine, would be found from the expression $Cl = \frac{100 \times 0.5 \times 0.96}{76} = 6.3$.

For the determination of hardness, pellets of potassium palmitate, made from a pill mass of glucose and potassium palmitate, are used. One hundred grams of glucose are used with an amount of potassium palmitate corresponding to 15 grams of palmitic acid. To make potassium palmitate, palmitic acid is dissolved in alcohol and neutralized with normal alcoholic potash solution, using phenolphthalein as indicator. The resulting alcoholic solution is then evaporated to dryness. The residue may be used without further treatment for making the pellets.

The following method is employed for the standardization of the pellets: A saturated solution of calcium hydroxide is prepared from pure calcium oxide. The normality of this is determined by titration of 25 cubic centimeters with 0.1 *N* sulphuric acid, using phenolphthalein as an indicator. One hundred cubic centimeters of the calcium hydroxide solution are then pipetted into a 200 cubic centimeter volumetric flask. A few drops of phenolphthalein solution are added, followed by normal sulphuric acid to acid reaction. Add 0.2 *N* alcoholic potash, drop by drop, until a faint pink is produced. Distilled water, which has been previously boiled to expel carbon dioxide, is added to the mark.

The calcium sulphate solution thus prepared is used to standardize the pellets. Five of these are crushed in a mortar with a little distilled water, and 5 drops of phenolphthalein are added. The standard calcium sulphate solution is then added from a burette, until the last trace of phenolphthalein pink disappears.

From the number of cubic centimeters used and the determined strength of the calcium hydroxide solution, the strength of the pellets, expressed in terms of calcium carbonate, is calculated.

Since a saturated solution of calcium hydroxide is about 0.04 *N*, the standard calcium sulphate solution as prepared above will be about 0.02 *N*, that is, 1 cubic centimeter will be equivalent to about 1 milligram of calcium carbonate.

The potassium palmitate tablets, as prepared above, will each be found to be equivalent to 1.5 to 2 milligrams calcium carbonate.

These pellets should be standardized every week, as they lose strength fairly rapidly. What this loss of strength is due to is not yet certain, but from the data at hand it seems at least possible that it may arise from an acid fermentation of the glucose, bringing about a decomposition of the potassium palmitate with the separation of palmitic acid.

For use in the determination of total hardness, 1 cubic centimeter graduation marks were etched on a 100 cubic centimeter cylinder, so that volumes up to 105 cubic centimeters could be read.

For a determination, 100 cubic centimeters of the water, measured in this cylinder, are transferred to a dry 250 cubic centimeter bottle (the glass-stoppered variety is convenient). A very small piece of methyl orange paper is suspended in the liquid by means of a platinum wire, while normal sulphuric acid is added from a dropping bottle until the paper becomes red. The paper is then removed to avoid coloring the liquid.

The liquid is then aspirated for five minutes with a continuous pressure bulb operated by hand. After aspiration, 1 cubic centimeter of phenolphthalein is added, followed by 0.2 *N* alcoholic caustic potash from a pipette, till a faint pink coloration develops. The liquid is now returned to the cylinder, the bottle being drained as completely as possible. The volume of the liquid is noted within 0.5 cubic centimeter. This will usually be between 102 and 105 cubic centimeters.

About 10 cubic centimeters of the liquid are then introduced into the mortar. One or more potassium palmitate pellets are then added, until an excess is present, that is, when a pronounced phenolphthalein coloration is produced. More water is then added from the cylinder, until the phenolphthalein coloration completely disappears. The volume of water used is noted. Several more pellets are then added, followed by water, till a second end point is reached. The two determinations should check each other within 0.5 to 1 cubic centimeter.

It is well to use four or five pellets in the two titrations to avoid any considerable error due to the lack of uniformity in the pellets.

To calculate the total hardness, it is first necessary to reduce the number of cubic centimeters of the water as used in the determination to the equivalent number of cubic centimeters of the original water, that is, before it was diluted with sulphuric acid, phenolphthalein, and alcoholic potash. Then the total hardness is computed from the value and number of the pellets used.

For example, let us suppose that the original volume of 100 cubic centimeters had been diluted to 104.5 cubic centimeters before titration with the palmitate pellets, each equivalent to 1.80 milligrams calcium carbonate. Obviously the 48.5 cubic centimeters used for the determination are equal to

$$\frac{48.5}{104.5 \times 100} = 46.4$$

cubic centimeters of the original water. Therefore the total hardness would be derived from the expression

$$\frac{1{,}000 \times 4 \times 1.80}{46.4}.$$

Or, using the data above, we may represent the entire calculation in one line as follows. Total hardness (as parts per million calcium carbonate) is equal to

$$\frac{10 \times 104.5 \times 4 \times 1.80}{48.5} = 155.$$

Total solids are estimated with the aid of Dole's formula,[154] slightly modified. For Philippine ground waters, the following will be found satisfactory:

$$100 + \text{normal carbonates (as } Na_2CO_3) + \text{bicarbonates (as } CaCO_3) + 1.7\ SO_3 + 1.6\ Cl.$$

Estimated encrustants are calculated (for the clear water) from Dole's formula:[155]

$$\text{Estimated encrustants} = \frac{\text{Bicarbonate alkalinity (as } CaCO_3) + CaSO_4 + \text{total hardness (as } Ca\ CO_3)}{2}.$$

[154] Dole, R. B., *U. S. Geol. Surv.*, *Water Supply Paper* (1916), No. 399, 304.

[155] *U. S. Geol. Surv.*, *Water Supply Paper* (1910), No. 254, 232.

Assuming the sulphates present to be there as calcium sulphate, the $CaSO_4$ in the above formula becomes 1.7 SO_3. In this form the formula is available for field work.

Classification for boiler use is based upon the amount of estimated encrustants, according to the scheme of the American Railway Engineers' Maintenance of Way Association, which has been quoted in the discussion on industrial waters.

The use of the Berkefeld army filter to clarify turbid waters, as suggested by Leighton, has been discontinued in our field work, and this for several reasons. Comparatively few of the waters examined on the average field trip are turbid. An analysis of only the clear portion of a turbid water is ordinarily not of great value, and when it is desired, a clear sample is readily obtained by sedimentation or by filtration through cotton or paper. Turbidity interferes appreciably only with the determination of sulphites. Its effect can be readily overcome by determining the turbidity of the liquid after adding hydrochloric acid and before adding barium chloride and subtracting this from the reading obtained after the sulphates have been precipitated. The difference represents the sulphate turbidity, and the amount of sulphates can be determined from the table without appreciable error. In short, the Berkefeld filter has found such limited application in our work that the minor benefits derived from its use have not been commensurate with the trouble and inconvenience of carrying it.

While field methods do not claim the exactness and accuracy possible in the laboratory, it is interesting to note that in several cases the values obtained by the two procedures do not differ very widely. As has been previously stated, results obtained in laboratory determinations are expressed in terms of two significant figures only. This mode of expression itself involves limits of accuracy, which permit a maximum error of about 4 per cent. The average accuracy of field determinations, as stated by Leighton and confirmed in our own work, is roughly about 5 per cent. Turbidity shows the widest variation, ranging from about 3 per cent with turbidities of 500 to 1,000 parts per million to about 16 per cent with a turbidity of 30 parts per million, the deviation increasing fairly regularly with decreasing turbidities.

There are several sources of probable error, of which the following are the most important. Using a 100 cubic centimeter graduated cylinder, volumes cannot be read more accurately than to the nearest tenth of a cubic centimeter and often

not that accurately. Further, when the mortar is washed with the water under examination, a certain amount remains in the mortar to affect the volume subsequently employed for the next titration. Further the lack of uniformity in the pellets may introduce a very appreciable error.

In our own work additional sources of probable error have been encountered with "tabloid" methods. Our pellets are molded by hand and are consequently not as uniform as machine-made pellets. This is especially true of the potassium palmitate pellets, which form a sticky pill mass that dries very quickly and that is very difficult to mold uniformly. Again kaolin is used in the sodium carbonate and silver nitrate pellets and obscures the end points, thus decreasing the accuracy of the determinations.

In the "tabloid" determinations outlined above our methods differ from Leighton's in that, in the determination of chlorides and of total alkalinity, Leighton treated a known quantity of water with an excess of reagent to obtain an end point, while in all cases we titrate a known amount of reagent with the water to secure an end point. The former method gives values that lie between certain limits, as the excess of reagent is added in the form of parts of a pellet, and consequently the exact amount of reagent required for the titration is not determined. By making the excess small, the deviation from the true value is correspondingly decreased.

By our method, however, the exact titrating volume required is determined quickly and fairly accurately. The approach to the end point is thus reversed. This probably introduces an error in the determination of chlorides, which is, however, certainly much less than that involved in Leighton's method. It should be also remembered that the standardization of the pellets is made in the same manner as the field determination, thus decreasing the probable error. In the case of the determination of alkalinity, however, where methyl orange or butter yellow is employed as indicator, the reversed approach to the end point (that is, from acid to alkali) is theoretically the more correct of the two procedures and should, therefore, further increase the accuracy of the method as outlined above.

Summing up the whole question of the accuracy of field methods, it might not be out of place to quote from the introduction of Leighton's paper:

> To the methods hereinafter proposed the term "assay" readily lends itself. There is no attempt at water analysis. The plan contemplates

the determination of ingredients which give to water certain well-known characteristic. The methods * * * have been found to be more nearly accurate than was at first anticipated, though this fact, it is believed, has not greatly increased their usefulness for the purpose in view. By their use, combined with a fair amount of common sense, the essential characteristics of waters can be ascertained at small expense. In almost every situation in which such determinations are significant they will afford sufficiently satisfactory data. In the case of finely balanced considerations of a purely physical, chemical, or geologic nature, however, they are practically useless. They are intended for practical purposes and have no place in pure science.

INTERPRETATION OF WATER ANALYSES

When a water is very good or very bad, the judgment of its quality is usually a simple matter. Unfortunately for the analyst, however, one cannot, generally speaking, classify waters as unqualifiedly "good" or "bad." Both in laboratory and in field work it is generally impracticable to make more than one examination, and it must be admitted that a single test frequently affords insufficient basis for the interpretation of results.

In passing judgment on the quality of water supply, one must know the purpose for which the water is intended. Water entirely unsuitable for one use may be well adapted to some other. Thus a supply that might be dangerous for drinking might be excellent for use in manufacturing processes; a hard water unsuited for laundry or boiler purposes or for soap manufacture might be advantageously used for brewing or irrigation; water with moderate salt content is often desirable for brewing, though it is unsuitable for soap manufacture; a water supposed to have great medicinal value might be unfit for boiler use.

Sufficient has been said in preceding discussions to show that many factors must be considered in passing judgment upon a water. Difficult as it is to set up arbitrary standards even for waters designed for industrial use, the problem of judging supplies intended for human consumption is even more difficult, for here the effect of various ingredients cannot be determined as accurately as it can be for technical applications.

Considering first the technical applications of water, some of which have been discussed under industrial supplies, the significance of various ingredients may be summarized briefly somewhat as follows:[156]

Free acids.—Free mineral acids rapidly corrode metal work, and in addition to this destruction may introduce a portion of the dissolved metal into the finished product. In the paper and textile industries acids rot and streak the fabrics, in addition to decomposing some of the chemicals and dyestuffs. In the Philippines, however, very few minerally acid waters are found.

[156] These statements, which are only general in character, are based chiefly on the classifications by Dole, R. B., *U. S. Geol. Surv., Water Supply Paper* (1910), No. 254, 232, and by Klut, H., *Eng. Rec.* (1910), 60, 498.

Total solids.—Over 300 parts per million of total solids (residue on ignition) generally make water undesirable for boiler purposes, although under certain conditions waters with many times as great a mineral content may be used.

Suspended matter.—Suspended matter is objectionable in all process in which water is used for washing or comes into contact with food materials. It frequently causes stains or spots. For this reason even a small amount of suspended matter due to precipitated iron is especially injurious. Suspended vegetable or animal material is liable to decomposition and partial solution. Water should be, therefore, freed from suspended matter before being used for laundering, dyeing, bleaching, starch and sugar making, brewing, distilling, and similar processes.

Color.—Color in water is due principally to solution of vegetable matter, though in freshly drawn spring and well water it may result from iron. The chief objection to color due to vegetable matter is in the paper and textile industries, where the finished product may be tinged.

Iron.—More than 0.1 part per million of iron may be objectionable in the industries. It forms greenish or black substances with materials containing tannin, which discolor hides in tanning and barley in melting, and which give beer bad color, odor, and taste. In all cleansing processes, especially if soap or alkali is used, precipitated iron is liable to cause rusty or dull spots. Waters containing large amounts of iron may develop growth of *Crenothrix,* a small filamentous plant colored with iron oxide, which clogs pipes, valves, and faucets and causes rust stains on clothes washed in the water.

Manganese.—In any appreciable quantity, manganese generally makes water unfit for industrial purposes.

Calcium and magnesium.—The effect of waters used for boiler purposes has been already discussed. For many other industrial purposes they are just as undesirable. In laundering, the soap (which is a compound of sodium or potassium with certain fatty acid radicals) is decomposed, with the formation of a curd of insoluble calcium or magnesium "soaps," which have no detergent or lathering properties. Soap will continue to be wasted, and no lather will be secured, until all the calcium and magnesium have been used up. Calcium carbonate wastes eight times its weight of soap. In laundries supplied only with hard water, softening is imperative.

High calcareous waters cannot be used in distilleries, because proper action is hindered by the deposition of alkaline earth

salts on the grain in boiling, nor can they be used for diluting spirits, because they cause turbidity.

In cooking, a hard water is objectionable, as a deposit of lime salts is formed upon the surface of tea leaves, meat, vegetables, etc., which hinders their extraction or hardens their tissues. It has been asserted that 'ten ounces of tea made with soft water is as strong as 18 ounces brewed with hard water'; and M. Soyer * * * proved that in the making of soup more meat is required with a hard water, and the operation takes a longer time. Vegetables have their colour darkened by the action of carbonate of lime. * * * In baking, the dough rises better, and the bread is lighter in colour, when soft water is used.[157]

The presence of calcium and magnesium compounds may sometimes be advantageous. Thus, in brewing certain beers and ales, calcium sulphate is desirable. In paper making slightly hard waters are preferable to very soft ones, as the latter dissolve part of the calcium sulphate used for loading.

Sulphates.—Hard waters with sulphates predominating are desirable in tanning heavy hides, because they swell the skins, exposing more surface for the action of the tan liquors. Sulphates interfere with crystallization in sugar making, so that the amount of sugar retained in the mother liquor is increased.

Chlorides.—More than 100 parts per million of chlorine may be injurious to plants; more than 200 are generally detrimental to boilers. Salty waters should not be used in concrete construction. In tanning, chlorides cause the hides to become thin and flabby. Waters with high salt contents obviously cannot be employed in soap making or in laundry work, as soap is insoluble in them.

Beverages and food products, of course, cannot be treated with waters very high in chlorides without becoming salty. In sugar making, the animal charcoal used in clarification is deprived of its bleaching power by absorption of salt, and saline salts are incorporated in the finished sugar crystals. In the preparation of alcoholic beverages chlorides in large amount prevent the growth of yeast and interfere with the germination of the grain.

Silica.—If present in large quantities, silica is considered objectionable for boiler purposes.

Nitrates.—A high nitrate content spoils water for brewing, fermentation, or sugar refining.

Ammonia.—Ammonia interferes with starch, brewing, or fermentation industries when more than a trace is present.

Carbon dioxide.—Free carbon dioxide as a rule accelerates corrosion.

[157] Rideal, S. and E. K., Water Supplies (1915), 141.

Hydrogen sulphide.—Hydrogen sulphide is poisonous. In addition, it is corrosive even in small quantities, and may also injure materials by discoloring and rotting them. This substance is associated with such large amounts of dissolved salts in many waters that they are unfit for industrial use for reasons other than their gaseous content.

Organic matter.—Organic matter of fæcal origin is, of course, dangerous in any water that comes into contact with food products. Even when not necessarily capable of producing disease, it is undesirable in industrial supplies because it induces decomposition in other organic materials, such as cloth, yarn, sugar, starch, meat, or paper, by rotting and discoloring them.

Other substances.—Other substances commonly occurring in Philippine waters are normally present in such small amounts as to render discussion of them unnecessary.

The changes that take place in a water sample on standing frequently help to make interpretation of analyses more difficult. As a typical instance may be mentioned the changes in carbon dioxide, carbonate, and bicarbonate content, previously discussed. These ingredients frequently change to such an extent that the analysis is misleading.

As was pointed out in the preceding chapter, the examination of water consists of three parts—chemical analysis, bacteriological examination, and sanitary survey. One of these is often sufficient to determine the potability. As a general rule, however, it is not enough to know that a water is good at the time of examination; it is just as essential to find out whether it has been contaminated in the past or whether it is subject to contamination in the future. All methods at our disposal are generally needed, therefore, to enable us accurately to judge the potability of a water.

Considering first the chemical features of a water examination, the common ingredients and properties of waters with respect to potability may be classified as follows:[158]

Color, odor, taste, turbidity.—The best water for drinking purposes is clear and is free from objectionable color, odor, or taste. Color and turbidity in themselves are not important except when they are caused by harmful or objectionable substances.

Total dissolved content.—The total dissolved content in itself has no significance. When the solid content is very high, waters are sometimes laxative or objectionable in taste.

[158] Cf. also Klut, loc. cit.; Dole, loc cit.

Hardness.—When hardness is high, it may affect the taste, but in itself it is of little importance hygienically.

Alkalinity.—Alkalinity is not believed to be as objectionable as it was formerly considered to be, some waters having an alkalinity of 900 to 1,200 parts per million being palatable and having no noticeable ill effect.[159]

Silica.—Silica in the quantities normally found in natural waters is not considered to have any appreciable effect on potability.

Chlorides.—Chlorides are generally an indication of the amounts of salt in water. Salt in itself is not objectionable, except in so far as it affects taste or indicates sewage pollution. In the latter case it is not the actual amount of salt present, but the deviation from the normal for any given district, that is the criterion. In some parts of the Philippines people have accustomed themselves to waters containing 800 parts of chlorine per million, and experience in this and other countries has demonstrated that such quantities in drinking water are not injurious to health per se.

Nitrogen.—The importance of nitrogen and the forms in which it may be present have been discussed under methods of analysis.

Aluminium.—Aluminium has no hygienic importance in the quantities normally found in water.

Iron.—Iron, like aluminium, has no significance in the small quantities normally found in water, but it is sometimes objectionable because it imparts an unpleasant taste to water and because it promotes the growth of *Crenothrix* in pipes and reservoirs. A good water usually contains less than 2 parts of iron per million.

Calcium.—Calcium has no significance so far as known.

Magnesium.—In the presence of sulphates, magnesium causes intestinal disturbances when present in large amounts.

Sodium.—Sodium and potassium have no significance.

Arsenic.—Arsenic is poisonous. At least one case is known where a natural water in the Philippines contained enough arsenic to be dangerous for drinking purposes.

Lead.—Lead is a cumulative poison whose presence renders water unfit to drink. It is seldom found in natural waters.

Copper, zinc, and tin.—Copper, zinc, and tin are not found in natural waters in objectionable quantities.

Sulphates.—(See Magnesium.) In themselves sulphates are unimportant. Over 500 parts per million can be present in

[159] Ruediger, E. H., *Am. Journ. Pub. Health* (1918), 3, 1904.

water without causing bad effects, though when present with magnesium, or even with sodium, large quantities sometimes cause intestinal disturbances.

Hydrogen sulphide.—Hydrogen sulphide is poisonous; hence it is objectionable in large quantities.

Oxygen-consuming capacity.—The oxygen-consuming capacity is an indication of organic matter and is often valuable when a fresh sample can be secured and when a water source can be kept under observation for some time. Philippine waters have not been sufficiently studied to enable a standard to be set up.

Dissolved oxygen.—Dissolved oxygen is a valuable indication of the purity of a water when the determination is performed at short intervals. It, too, can be measured only in fresh samples.

From the foregoing it is evident that, in general, the mineral content of a water may vary within wide limits without affecting its potability. It is further evident that hard and fast standards cannot be set up. It is the exception, rather than the rule, that the substances found in water by chemical analysis are in themselves injurious to health.

The object of a chemical analysis, therefore, is not usually the discovery of harmful ingredients, but the determination of substances whose presence or absence indicates the possibility of contamination by material dangerous to health. Thus in making a sanitary analysis of waters, it has been customary to determine, among other things, the chloride content. Chlorides, generally present as common salt, are neither poisonous nor dangerous. However, they are found in sewage; hence a high chlorine content, or a sudden variation in the content, might be due to an influx of sewage and must be viewed with suspicion. A variation in chloride content, as, for example, a sudden shift from 50 to 150 parts per million, is to be viewed with suspicion, whereas a constant chloride content of 200, or even of 250 parts per million would not indicate contamination. It is necessary to determine the normal mineral content of waters in different localities and to base judgment of waters on their deviations from such normals. Unfortunately the work done in the Philippines has been insufficient to develop normals, and as pointed out previously the waters from comparatively small districts in the Philippines show such great fluctuations that it does not appear probable that they can be developed for some time to come. Since standards, to be reliable, must be based on normals, it is clear not only that no arbitrary standards can be set up for the Philippines at the present time, but also that

the application of foreign standards will lead to confusing or incorrect results.

The many attempts that have been made to develop bacteriological standards of purity for water have shown that bacteriological examination, like chemical analysis, must be interpreted with great caution and in conjunction with other essential factors to ensure satisfactory conclusions. Also, as with chemical analysis, only the very good or very bad waters are easily classified.

Because of the essentially different bacteriological character of waters from different types of sources, it is extremely unlikely that a single fixed standard can be developed. The organisms normally found in certain classes of waters might indicate a high degree of pollution in others. A river free from pathogenic organisms might have a colony count high enough to cause a deep well to be viewed with suspicion.

A water that has a high bacterial count is obviously undesirable for human consumption, for the presence of many organisms, even harmless ones, indicates, other things being equal, that pathogenic organisms may readily find access to the water. Just what limit shall be fixed, however, is not easy to say. The standard adopted by the United States Treasury Department for drinking water supplied to the public by common carriers in interstate commerce [160] provides that the total number of bacteria on standard agar plates, incubated for twenty-four hours at 37°, shall not exceed 100 per cubic centimeter. For public water supplies obtained from a river Frost [161] recommends a limit of 100 colonies per cubic centimeter on agar plates incubated for forty-eight hours at 20° and states that a really good water should show not more than from 10 to 50 colonies per cubic centimeter on standard agar incubated at 37° C.

A factor that frequently increases the difficulty of interpreting bacteriological colony counts is the rapidity with which changes take place in the number of organisms existing in water. It has been estimated [162] in the United States that un-iced specimens of water examined twenty-four hours after collection may safely contain 200 colonies (agar plates; 20° C. incubation) and that from forty-eight to seventy-two hours after collection 500 colonies may result. Though the authors conclude that the

[160] Anderson, J. F., et al., *U. S. Pub. Health Rep.* (1914), 29, 2959–2966; *Eng. News* (1914), 72, 1203–4.

[161] Frost, W. H., *Eng. Contr.* (1914), 42, 250, through *Chem. Abst.* (1914), 8, 3606.

[162] Albert, H., Hinman, J. J., and Jordan, G., *Journ. Bact.* (1916), 1, 119.

results of tests on un-iced specimens may be relied upon if properly (?) interpreted in the light of sanitary survey, great dependence cannot be placed on such methods. Especially in tropical countries like the Philippines the high average temperature, as compared with that of a temperate country, makes fluctuations more rapid and much greater than the figures just quoted indicate.

The examination for organisms of the colon-typhoid group is a test, not so much for specific bacteria that are inimical to health, but rather for those, more readily determined, that indicate the possibility of the presence of associated pathogenic organisms. In general, the occasional presence of *B. coli* in very small numbers is considered permissible. According to Anderson and others [163] not more than one out of five 10 cubic centimeter portions of a water sample should show organisms of the *B. coli* group; according to Frost [164] these organisms should never be found in 1 cubic centimeter samples and should be absent in from 70 to 90 per cent of samples of 10 cubic centimeters. According to McLaughlin [165] potable water should show not more than 2 *B. coli* per 100 cubic centimeters, taking the average of many samples by the Phelps method.

Unfortunately the test for the *B. coli* group, as usually performed, is by no means conclusive. It has been demonstrated that organisms resembling *B. coli* in their behavior, but not of fæcal origin, are found in surface waters even in temperate climates.[166] Certain cultures from grains belong to this type. Abundant experience in tropical water-supply problems [167] has shown that a presumptive test for the colon group can be obtained under conditions that practically exclude the possibility of fæcal contamination. Waters from almost sterile wells in the Philippines have caused gas formation in litmus lactose agar. Zammit and Marich [168] record instances where springs in Malta, believed to be uncontaminated, showed *coli*-like organisms, as did even carefully collected rain water.

To what extent the standards just discussed are applicable to Philippine problems is not established. They are typical of standard procedure elsewhere and may serve as a basis for

[163] Op. cit.
[164] Loc. cit.
[165] McLaughlin, A. J., *Pub. Health Rep.* (1914), No. 204.
[166] Rogers, L. A., *Journ. Bact.* (1916), 1, 82.
[167] Clemesha, W. W., *Journ. Hyg.* (1912), 12, 463.
[168] Zammit, T., and Marich, E. R., *Journ. State Med.* (1916), 24, 76–81.

future work. It is certain, however, that the standards that hold for temperate regions are not to be used without modification for tropical countries. This has been pointed out in connection with the various factors already discussed and is supported by the evidence from other countries. Thus Bowles [169] has shown the inapplicability of ordinary bacteriological standards to the water-supply problems in Panama and Mexico. So far as experience in the Philippines is concerned, the following general statements concerning bacteriological interpretation seem justified:

Flowing artesian wells are practically sterile.

Deep pumping wells in good condition are very low in bacterial content. The colony count should not run over 50 per cubic centimeter. If a higher bacterial content is indicated, an examination of the pump should be made, as this is frequently the source of contamination. If the high content is not due to the pump, as demonstrated by a second test after necessary repairs have been made and the well has been subjected to a thorough pumping, contamination is indicated, and the water is not above suspicion.

Springs, in general, are more liable to contamination than deep wells; hence they must be examined with special care. To be above suspicion, a spring water should show less than 50 colonies per cubic centimeter.

Surface wells in the Philippines, with comparatively few exceptions, are subject to contamination and must be viewed with suspicion, regardless of the bacterial content indicated by a single examination.

Rivers in the Philippines, unless draining a district known to be uninhabited, are to be viewed with suspicion, even though a single bacteriological examination might show them to be satisfactory at the time of examination.

Bottled natural and carbonated waters should be sterile.

The presumptive test for *B. coli* must be interpreted liberally, in conjunction with the chemical analysis and the sanitary survey. A positive presumptive test obtained from a water that shows only a low colony count is not conclusive.

The scope and possibility of the sanitary survey have been already described and need no detailed explanation here. Each case presents individual characteristics and problems, the proper interpretation of which depends upon the ingenuity and expe-

[169] Bowles, J. T. B., *Am. Journ. Pub. Health* (1916), 6, 1173.

rience of the man in the field. It cannot be too strongly emphasized that an intelligent study should be made of the source of every water of which analysis is requested, and further that, whenever possible, this survey should be made by the person called upon to interpret the analysis.

Before leaving this subject, it may be mentioned that evidence other than that furnished by the ordinary examination may be needed to establish the quality of a water. Special methods are frequently adopted to secure such evidence. Thus connection between a well and a possible source of pollution may be occasionally demonstrated by placing a kilogram or two of salt on the suspected area and noting any appreciable rise in the chlorine content of the water. Fluorescin may be used for the same purpose, its presence giving a characteristic fluorescence to water. Or, since liquids might filter unchanged through a soil that would remove bacteria, a culture of some easily recognized organism might be used instead of salt or fluorescin. *Bacillus prodigiosus* has been so used with satisfactory results.

The problem of judging the potability of waters can be summarized somewhat as follows: Each water should be regarded as a separate case and should be judged accordingly. One of the special advantages of a chemical analysis lies in the fact that it sometimes gives an indication of pollution in the past; hence the possibility of recurrence of contamination, in cases where bacteriological examination gives no indication of danger. A bacteriological examination is extremely valuable in that it makes contamination evident even in some cases in which neither chemical analysis nor a sanitary survey would detect pollution. On the other hand, neither chemical nor biological work might detect a source of danger that a sanitary survey would locate. Chemical and biological examinations are complementary; neither is all-sufficient; and valuable as both are, they should be carefully interpreted in the light of the knowledge gained by an accurate and painstaking sanitary survey.

TABLE XI.—*Ground-water springs of the Philippine Islands.*

Locality. (Province, town, barrio.)	Date.	Temperature.	Turbidity.	Alkalinity.	Acidity.	Iron (Fe).	Chlorides (Cl).	Normal carbonates (Na_2CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Total hardness.	Estimated incrustants.	Classification for boiler use.	Colonies per cubic centimeter.	Presumptive test.
		°C.													
Cebu, Alcantara, poblacion	1916	28.0	nil	370	23		2,530	nil	450	360	710	850	Very bad	45	Negative.
Cebu, Alegria, poblacion	1916	27.5	nil	380	30	0.13	12.5	nil	460	60	380	430	Bad	11	Do.
Cebu, Asturias, poblacion	1916	29.0	nil	410	22	0.33	10	nil	560	nil	290	350	Poor	8	Do.
Cebu, Asturias, Langub	1916	26.3	nil	290	14	0.33	6.3	nil	350	nil	310	300	do	6	Do.
Cebu, Badian, poblacion	1916	24.5	nil	270	14	0.84	15	nil	330	trace	220	245	do	70	Do.
Cebu, Balamban, Aliwanay	1916	26.5	nil	340	20	1.0	6.0	nil	415	14	400	380	Poor	40	Do.
Cebu, Balamban, Pondol	1916													6	Do.
Cebu, Barili, Buluc-Buluc	1916	31.5	nil	460	33	0.77	20	nil	560	78	420	500	Bad	2	Do.
Cebu, Barili, Mantayupan	1916	24.3	nil	340	20	nil	7.0	nil	410	trace	270	300	Poor	43	Do.
Cebu, Barili, Gitnangan	1916	29.0												6	Do.
Cebu, Dumanjug, Kanagtol	1916	27.0	73	350	33	0.13	14	nil	46	46	330	380	Poor	180	Positive.
Do	1916	28.0	nil	360	33	0.07	18	nil	440	40	310	360	do	14	Negative.
Do	1916	28.0	nil	360	34	0.07	19	nil	440	38	320	370	do	8	Do.
Cebu, Ginatilan, poblacion	1916	27.5	nil	440	22	3.0	6.7	nil	540	trace	310	380	do	5	Do.
Cebu, Ginatilan, Guiwanon	1916	26.0	nil	370	29	0.47	36	nil	450	36	330	375	do	1	Do.
Cebu, Ginatilan, poblacion	1916	27.0												27	Do.
Do	1916	28.0												4	Do.
Cebu, Malabuyoc, Sorsogon	1916	26.0	nil	440	27	1.1	14	nil	540	29	380	430	Bad	0	Do.
Cebu, Malabuyoc, Armenia	1916	27.0	nil	530	46	1.9	10	nil	650	28	400	480	do	17	Do.
Cebu, Malabuyoc, Ynamblan	1916	60.0	nil	340	34	0.13	110	nil	415	110	310	400	Poor	2	Do.
Do	1916	33.0	58	370	18	2.2	17	nil	450	35	260	340	do	18	Do.
Cebu, Malabuyoc, Pangi	1916	27.0	70	380	30	trace	7.0	nil	460	trace	310	345	do	500	Do.
Cebu, Moalbual, Pangi	1916	28.0	nil	380	34	1.1	11	nil	460	trace	320	350	do	18	Do.
Cebu, Naga, Uling	1917	26.0	nil	270	73	nil	7.0	nil	330	300	1,300	1,100	Very bad	115	Do.
Do	1917	24.0	175	170	20	0.83	4.0	nil	210	trace	310	240	Poor	4,300	Positive.

TABLE XI.—*Ground-water springs of the Philippine Islands*—Continued.

Locality. (Province, town, barrio.)	Date.	Temperature.	Turbidity.	Alkalinity.	Acidity.	Iron (Fe).	Chlorides (Cl).	Normal carbonates (Na_2CO_3).	Bicarbonates (HCO_3)	Sulphates (SO_4).	Total hardness.	Estimated incrustants.	Classification for boiler use.	Colonies per cubic centimeter.	Presumptive test.
		°C.													
Cebu, Pinamungahan, poblacion	1916	27.5	nil	540	30	0.13	100	nil	660	22	490	530	Bad	40	Negative.
Cebu, Ronda, Magtubud	1916	27.5	63	320	38	0.73	10	nil	390	28	310	330	Poor	45	Do.
Cebu, Samboan, poblacion	1916	27.0	nil	390	37	0.13	10	nil	480	18	350	380	do	7	Do.
Do	1916	28.0	nil	350	28	0.4	5.6	nil	430	trace	310	330	do	2	Do.
Cebu, Toledo, Ibo	1916	27.0	nil	460	40	0.03	7.0	nil	560	24	420	460	Bad	90	Do.
Cebu, Tuburan, Marmol	1916	25.5	nil	440	35	0.13	6.0	nil	540	nil	340	390	Poor	2	Do.
Laguna, Calamba, Bocal	1916	31.0	nil	190		0.17	39	nil	230	24	99				
Do	1916	31.0	nil	220		0.33	66	nil	270	26					
Laguna, Calamba, Pansol	1916	44.5	nil	200		nil	230	nil	240	55	110				
Laguna, Calamba, Canlubang	1916	26.5	nil	180	32	0.2	5.6	nil	220	10	120	160	Fair	15	Do.
Do	1916	28.0	nil	130	28	0.05	8.9	nil	160	12	120	130	do	70	Do.
Laguna, Lilio	1916	23.0	trace	93	34	0.1	8.0	nil	110	trace	66			3	Do.
Do	1916	22.2												5	
Laguna, Lilio, Bacal	1916	22.0	nil	91	25	0.1	8.0	nil	110	trace	60			15	Do.
Laguna, Los Baños, poblacion	1916	25.5	trace	30	46	0.2	8.0	nil	37	15	21	38	Good	90	
Do	1916	70.5	nil	220	31	0.17	540	nil	270	32	170	220	Poor	0	Do.
Laguna, Majayjay	1916	20.5	nil	35	13	0.1	6.0	nil	43	trace	25				
Laguna, Majayjay, Otta	1916	22.0	nil	56	18	0.25	7.0	nil	68	trace	30				
Do	1916	24.0	nil	86	11	0.25	5.0	nil	105	trace	58				
Laguna, Majayjay	1916	25.0	slight	46	trace	2.0	7.0	nil	49	trace	22			212	Positive.
Laguna, Nagcarlan, San Vicente	1916	21.5	nil	58	22	0.1	6.0	nil	71	16	33			5	Negative.
Laguna, Nagcarlan, San Diego	1916	25.0	nil	130	64	0.1	8.0	nil	160	13.0	97			8	
Laguna, Paete, town	1916	25.0	nil	130	22	0.3	8.8	nil	160	trace	100			300	Positive.
Do	1916	25.5	nil	120	23	0.5	8.8	nil	150.0	nil	89			65	Do.
Do	1916	25.0												600	Do.

Laguna, Pagsanjan, Pinagsanjan	1916	31.0	nil	170	40	nil	22	nil	210	trace	110			(?)	
Laguna, Pakil, town	1916	25.5	nil	120	19	0.25	9.0	nil	150.0	trace	95			5	Negative.
Laguna, San Pablo	1916	27.1	nil	210	59	0.17	12	nil	250	16	155			15	Do.
Laguna, San Pablo, Cabunsud	1916		nil	110	23	0.07	14	nil		23	65	110	Fair	23	Do.
Misamis, Balingasag, San Ignacio	1916	26.8	nil	100	9.0	0.2	2.6	nil	120	14	120	120	do	55	Do.
Misamis, Cagayan, Gusa	1916	26.3	nil	330	42	0.8	3.0	nil	400		430	380	Poor	8	Do.
Misamis, Cagayan, Taguanao	1917	26.6	opales'nt	360	26	0.07	6.0	nil	440	nil	460	410	do	70	Do.
Misamis, Misamis, Kabungaan	1917	24.0	nil	160	18	0.07	6.0	nil	195.0	nil	155	160	Fair	1	Do.
Misamis, Misamis, Karangan	1917	25.3	nil	150	13	0.07	40	nil	180	nil	160	155	do	10	Do.
Mountain, Benguet, Ambuklao, north of presidencia	1917	26.7	nil	57	21	0.13	2.5			89	86	135	do		
Mountain, Benguet, Ambuklao, southwest of presidencia	1917	26.0	nil	48	15	0.07	2.8			73	82	120	do		
Mountain, Benguet, Baguio on Bua Road	1917	22.7	nil	8.3	4.8	0.07	2.5			trace	<10	<10	Good		
Mountain, Benguet, Baguio, Consolidated Mine	1917	23.5	nil	52	13	1.5	6.8			460	large				
Do	1917	24.8	trace	83	<4	0.17	3.6			240	170	300	Poor		
Mountain, Benguet, Baguio, Dominican Hill	1917	20.4	trace	60	14	0.07	2.5			trace	40	60	Good		
Mountain, Benguet, Baguio, Federle's	1917		nil	60	16	nil	3.3			trace	40	50	do		
Mountain, Benguet, Baguio, near Government Center	1917	22.4	nil	5	22	0.07	2.5			19	<10	trace	do		
Mountain, Benguet, Baguio, Headwaters Mine	1917	21.3	slight	95	<5	0.13	3.1			36	80	110	Fair		
Mountain, Benguet, Bokod, Daklan	1917	60.5													
Mountain, Benguet, Bokod, Daklan, Asin, sitio	1917	52.0	nil	310	100	2.0	4,700			78	950	685	Very bad		
Mountain, Benguet, Bokod, Daklan	1917	21.8	nil	100	7.0	0.07	<2.5			nil	66	83	Good		
Mountain, Benguet, Bokod, Daklan, Palungod, sitio	1917	24.8	nil	100	18	0.13	<2.5			trace	58	79	do		

TABLE XI.—*Ground-water springs of the Philippine Islands*—Continued.

Locality. (Province, town, barrio.)	Date.	Temperature.	Turbidity.	Alkalinity.	Acidity.	Iron (Fe).	Chlorides (Cl).	Normal carbonates (Na_2CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Total hardness.	Estimated incrustants.	Classification for boiler use.	Colonies per cubic centimeter.	Presumptive test.
		°C.													
Mountain, Benguet, Buguias, north of presidencia	1917	59.8													
Mountain, Benguet, Buguias, southwest of presidencia	1917	48.1	nil	51	nil	nil	12.5	trace		320	155	335	Poor		
Mountain, Benguet, Buguias	1917	45.5	nil	56	<1.5	nil	17.0			320	160	340	do		
Do	1917	57.5	nil	580	58	3.0	5,400			280					
Mountain, Benguet, Kabayan	1917	20	nil	87	<5	0.07	3.3			29	70	99	Fair		
Do	1917	21	nil	22	13	0.07	2.7			132	100	160	do		
Mountain, Benguet, Lutab	1917	22.5	nil	78	6.1	0.07	3.1			240	115	270	Poor		
Mountain, Benguet, Trinidad Headquarters, rear of Constabulary.	1917	23.0	nil	24	35	0.07	3.9			trace	<10	17	Good		
Mountain, Benguet, Trinidad, poblacion.	1917	20.8	nil	33	12	0.07	3.8			nil	14	24	do		
Mountain, Ifugao, Awa	1917	20.5	nil	49	<2.5	nil	2.6			trace	39	45	do		
Mountain, Ifugao, Banaue	1917	23.3	nil	100	32	0.13	3.8			nil	85	93	Fair		
Mountain, Ifugao, Banaue, Ingulley, north of school.	1917		nil	120	18	nil	<2.5			nil	105	110	do		
Mountain, Ifugao, Banaue, sitio Kiakap.	1917		nil	105	4.6	0.13	<2.5			nil	72	88	Good		
Mountain, Ifugao, Banaue, sitio Paypayan.	1917	21.4	nil	94	16	nil	4.5			nil	75	85	do		
Mountain, Ifugao, Kiangan, Adlong.	1917	19.7	nil	160	13	0.2	2.5			24	150	170	Fair		

Mountain, Ifugao, Kiangan, Adukpung.	1917	24.6	nil	185	38	0.13	7.0	------	------	56	170	220	Poor ------	------	
Mountain, Ifugao, Kiangan, Adungbu.	1917	24.7	nil	230	37	0.33	2.5	------	------	49	230	265	----do ------	------	
Mountain, Ifugao, Kiangan, Atuda.	1917	21.8	opales'nt	140	nil	0.20	2.5	trace	------	20	110	140	Fair ------	------	
Mountain, Ifugao, Kiangan, Lakdo.	1917	21.8	nil	37	19	0.13	2.5	------	------	trace	25	31	Good ------	------	
Mountain, Ifugao, Kiangan, Lubungan.	1917	24.4	nil	195	23	0.13	3.0	------	------	40	180	220	Poor ------	------	
Mountain, Ifugao, Kiangan, Malpao.	1917	23.0	nil	230	21	0.53	<2.0	------	------	78	220	280	----do ------	------	
Mountain, Ifugao, Kiangan, Piko.	1917	23.2	nil	250	15	0.13	2.9	------	------	168	280	380	----do ------	------	
Mountain, Ifugao, Sapao ------	1917	22.5	nil	50	<2.5	0.13	2.5	------	------	trace	43	47	Good ------	------	
Nueva Vizcaya, Bagabag, Baños ------	1917	26.5	nil	195	15	0.47	8.3	------	------	19	190	210	Poor ------	------	
Nueva Vizcaya, Bagabag, San Luis.	1917	26.6	nil	210	17	0.67	<2.5	------	------	trace	170	190	Fair ------	------	
Nueva Vizcaya, Bayombong, Bangan.	1917	27.0	opales'nt	nil	61	6.3	<2.5	------	------	42	<7	------	------	------	
Nueva Vizcaya, Bayombong, Bascaran.	1917	25.5	trace	240	23	1.0	3.1	------	------	103	210	300	Poor ------	------	
Nueva Vizcaya, Imugan ------	1917	[a]22.0	nil	100	11	0.13	3.9	------	------	nil	100	100	Fair ------	------	
Nueva Vizcaya, Imugan, Nozo ------	1917	23.6	nil	100	6.7	0.33	<2.5	------	------	nil	82	91	----do ------	------	
Nueva Vizcaya, Imugan, Santa Fe ------	1917	22.0	nil	130	7.1	0.13	3.3	------	------	trace	130	130	----do ------	------	
Nueva Vizcaya, Orioung ------	1917	29.8	trace	290	20	0.67	3.6	------	------	trace	270	280	Poor ------	------	
Nueva Vizcaya, Santa Cruz, Salinas.	1917	31.3	nil	3,700	2,400	1.2	22,000	nil	------	900	------	------	------	------	
Nueva Vizcaya, Solano ------	1917	27.5	nil	160	24	0.33	6.3	------	------	19	170	180	Fair ------	------	
Occidental Negros, Bago ------	1917	28.5	nil	85	48	nil	4.2	nil	100	6	------	------	------	180	Positive.
Occidental Negros, Hinigaran, Naravis.	1917	------	trace	40	5.7	0.73	3.0	nil	49	------	------	------	------	450	Do.
Occidental Negros, Isabela, Mambahao.	1917	35.4	trace	220	290	1.87	46.0	nil	270	220	------	------	------	200	Do.

[a] Estimated.

TABLE XI.—*Ground-water springs of the Philippine Islands*—Continued.

Locality. (Province, town, barrio.)	Date.	Temperature.	Turbidity.	Alkalinity.	Acidity.	Iron (Fe).	Chlorides (Cl).	Normal carbonates (Na_2CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Total hardness.	Estimated incrustants.	Classification for boiler use.	Colonies per cubic centimeter.	Presumptive test.
		°C.													
Occidental Negros, La Carlota, Canlaon, hacienda.	1917	26.5	nil	77	35	0.07	7.6	nil	94	trace	110	93	Fair	38	Negative.
Occidental Negros, Isabel, hacienda.	1917	25.6	nil	57	34		9.0	nil	70	20	160	120	do	9	Do.
Occidental Negros, La Carlota, Canlaon, hacienda.	1917	25.5	nil	74	33	0.07	5.0	nil	90	trace	95	85	Good	15	Do.
Occidental Negros, Isabel, hacienda.	1917	26.3	nil	79	46	0.13	6.0	nil	96	20	240	170	Fair	85	Do.
Occidental Negros, Manapla, poblacion.	1917	27.0	nil	93	59	0.07	11.0	nil	110	nil				49	Do.
Do	1917	27.0	nil	130	71	0.07	25	nil	160	nil				4	Do.
Do	1917	27.3	nil	205	42	2.1	250	nil	250	36				28	Do.
Occidental Negros, Talisay, Kabanbanan.	1917	28.5	nil	120	53	8.0	3.0	nil	150	nil				2	Do.
Rizal, Antipolo, poblacion	1916	27.0	opales'nt	91	80	0.17	6.0	nil	110	nil	93	92	do	85	Not always positive in 1 c. c.
Do	1916	27.0	opales'nt	130	50	0.28	7.0	nil	160	nil	85	110	do	110	Negative.
Do	1916	27.5	nil	140	52	0.2	8.0	nil	170	nil	120	130	do	2	Do.
Rizal, Mariquina, Bayan-bayanan	1916	27.5	nil	290	34	1.5	10	nil	350	trace	110	200	Poor	2	Do.
Rizal, Mariquina, Tañon	1916	28.0	nil	210	34	0.2	10	nil	260	trace	88	150	Fair	15	Positive.
Rizal, Montalban	1916	27.6	nil	180	42	0.03	13	nil	220	trace	91	140	do	30	Negative.
Rizal, Montalban, San Rafael	1916	27.0	nil	73	79	0.03	25	nil	89	60.0	94	130	do	5	Do.
Rizal, Pasig, Bagong-Ilog	1916	28.5	nil	240	9.0	0.57	39	nil	290	nil	60	150	do	155	Positive.
Rizal, San Mateo, Patiis	1916	26.7	nil	170	40	0.07	12	nil	210	17	69	130	do	25	Do.
Rizal, San Mateo	1916	28.0	nil											103	Do.

Sorsogon, Bacon, town	1916	28.0	nil	120	34	nil	14	nil	150	12	83	110	Fair		
Sorsogon, Bacon, Burabud	1916	27.8												22	Do.
Sorsogon, Bacon, Santa Cruz	1916	26.3	nil	110	45	nil	11	nil	130	8.0	75	100	Fair	15	Negative.
Sorsogon, Bacon	1916		nil	120	30	0.2	13	nil	150	16	88	120	do		
Sorsogon, Bacon, San Roque	1916	26.0	nil	110	21	nil	14	nil	130	16	85	110	do	325	Positive.
Do	1916	26.5	nil	120	19	nil	13	nil	150	16	86	110	do	33	Do.
Sorsogon, Barcelona, Lagu	1916	27.5	nil	66	68	0.2	18	nil	80.5	trace	66	66	Good	14	Negative.
Sorsogon, Bulusan, Madlaon	1916	21.8	nil	81	60	trace	15	nil	99	trace	48	65		24	Do.
Sorsogon, Bulusan, Bujan	1916	44.5	nil	1,000	528	11	635	nil	1,200	25	1,100	1,100	Very bad	0	Do.
Do	1916	28.7	slight	51	trace	0.5	36	nil	62	20	39	60	Good		
Sorsogon, Castilla, Dancalan	1916	26.5	nil	160	53	0.1	18	nil	195	trace	95	130	Fair	17	Do.
Sorsogon, Dimas-Alang, Palinas	1916	28.0	nil	510	81	nil	28	nil	620	17	280	410	Poor	4	Do.
Sorsogon, Dimas-Alang, Uson	1916	30.8	nil	450	44	nil	20	nil	550	trace	300	380	do	33	Positive.
Sorsogon, Donsol	1916	27.2	trace	380	47	trace	21	nil	460	trace	230	310	do	100	Negative.
Sorsogon, Gubat, Bulacao	1916	26.2	nil	58	35	0.2	13	nil	71	trace	44	51	Good	312	Positive.
Sorsogon, Irosin, San Agustin	1916	28.2	nil	250	nil		35	trace	305	73	150	260	Poor	40	Do.
Sorsogon, Irosin, Bagsagan	1916	26.5	nil	160	37	0.15	16	nil	195	20	110	150	Fair	75	Do.
Sorsogon, Irosin, San Roque	1916	23.0	nil	57	trace		11	nil	70	15	59	72	Good	65	Do.
Do	1916	22.0	nil	77	trace	0.1	8.0	nil	94	14	67	84	do	400	Do.
Sorsogon, Irosin, Patag	1916	25.8	nil	88	45	trace	17	nil	110	20	130	130	Fair	7	Negative.
Sorsogon, Irosin, San Agustin	1916	28.0	nil	240	nil	0.1	32	trace	290	60	250	300	Poor	35	Do.
Sorsogon, Magallanes	1916	27.0	nil	150	42	nil	14	nil	180	trace	100	130	Fair	6	Do.
Sorsogon, Magallanes, Aguaga	1916	26.7	nil	150	60	nil	22	nil	180	trace	96	120	do	25	Do.
Sorsogon, Matnog	1916	25.7	slight	63	17		27	nil	77	trace	60	62	Good	350	Positive.
Sorsogon, Pilar, town	1916	27.0	nil	330	17	trace	23	nil	400	trace	160	250	Poor	24	Negative.
Sorsogon, Pilar	1916	26.8	nil	140	29	0.1	24	nil	170	trace	84	110	Fair	390	Positive.
Sorsogon, San Fernando, Dapian	1916	26.6	nil	500	90	0.1	27	nil	610	trace	290	400	Poor	95	Do.
Do	1916	26.6	nil											23	Negative.
Sorsogon, Santa Magdalena, town	1916	28.6	trace	88	66	0.1	23	nil	110	trace	77	83	Good	10	Do.
Sorsogon, Santa Magdalena	1916	26.0	nil	140	34		20	nil	170	trace	95	120	Fair	50	Positive.
Sorsogon, Sorsogon, town	1916	27.0	39.0	130	44	0.3	18	nil	160	12	110	130	do	17,000	Do.

TABLE XII.—*Spring waters*

Laboratory No.	Year.	Location. (Province, town, barrio.)	Source.	Temperature.
				°C.
118745	1914	Albay, Tiwi	Tiwi	
60883-1	1908	Albay, Tabaco	Tancalao	
60883-2	1908	do	do	
9704	1904	Ambos Camarines, Lagonoy, Goa	Lalo	
115071	1913	do	Lanot	
101757	1912	Ambos Camarines, Paracale	Ginobatan	
101757	1912	do	Cabeza Reginos	
12568	1904	Ambos Camarines, Pasacao	Punta Mainit	hot
119649	1915	Antique	Apdo	48.9
121856	1916	Antique, San José de Buenavista	Tuban	
18654-1	1905	Bataan, Dinalupijan	Hot Spring	hot
18654-2	1905	do	Tibio No. 2	warm
18654-3	1905	do	Tibio No. 3	warm
105433	1912	Bataan, Mariveles	Balong Anito	37
115732	1913	Batangas, Balayan, Gapas		
84437	1910	Batangas, Taal		
84438	1910	do		
84439	1910	do		
84440	1910	do		
124202	1917	Batangas, Tanauan, Ambulong		nonthermal
119022	1914	Bohol, Anda, Ylaya		
97865	1912	Bohol, Duero		
93928	1911	Bohol, Loay		
97168	1912	Bohol, Tubigon		
120478	1915	do	Ubuhan	
119828	1915	Bulacan, San Miguel de Mayumo	Sibul Springs	
124388	1917	Bulacan, Santa Maria, San Jose		
115229	1913	Capiz, Dumalag, Sohut		
122140	1916	do		
	1913	Cavite, Silang	Lucsuhen	
	1911	Cebu, Barili	Bolok-bolok	31.1
114039	1913	Cebu, Carcar	Spring	
	1910	Cebu, Carcar, Guadalupe	do	34.2
37929	1906	Cebu, Danao, Tehampie	do	
120479	1915	Bohol, Loay (?)	Tocdog	
51541	1907	Cebu, Mandaue	Spring	
	1910	Cebu, Naga	Mainit—North	34.5
	1910	do	Mainit—South	34.5
	1910	Cebu, Oslob, Mainit	Spring A	35.0

[a] $Fe_2O_3+Al_2O_3$.

[b] Potassium (K), 8.1; sodium (Na), 19.

[c] Turbid; turbidity not determined quantitatively.

[d] Sodium (Na), 355; manganese (Mn), strontium (Sr), potassium (K), lithium (Li), traces.

[e] Manganese (Mn), 2.2; alumina (Al_2O_3), 2.3; sodium (Na), 110; phosphoric acid (PO_4), potassium (K), trace.

[f] Alumina (Al_2O_3), trace; sodium (Na), 88.

[g] Phosphoric acid (PO_4), lithium (Li), trace; manganese (Mn), 9.4; alumina (Al_2O_3), 170; potassium (K), 17; sodium (Na), 45.

[h] Metaboric acid (BO_2), lithium (Li), trace; manganese (Mn), 11; alumina (Al_2O_3), 75; potassium (K), 10; sodium (Na), 24.

of the Philippine Islands.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Miscellaneous.
-------	-------	-------	180	630	[a]7.6	11	2.9	4.3	-------	-------	26	(b)
-------	-------	-------	-------	100	250	260	75.5	trace	-------	-------	2,100	(g)
-------	-------	-------	-------	90	120	150	28	trace	-------	-------	1,100	(h)
(c)	-------	-------	1,900	130	6.3	220	79	400	high	-------	79	(d)
(?)	-------	-------	650	160	17	42	24	160	nil	280	22	(e)
-------	-------	-------	97	-------	-------	-------	-------	14	-------	-------	-------	-------
-------	-------	-------	150	-------	-------	-------	-------	15	-------	-------	-------	-------
-------	-------	-------	505	46.5	-------	51	27	52	-------	-------	32	(f)
(c)	-------	-------	10,500	50	2	790	8.8	5,600	nil	5	trace	-------
nil	250	nil	370	69	0.2	38	20	22	nil	300	4.5	-------
-------	-------	-------	1,900	120	trace	83	92	650	30	415	53	(i)
-------	-------	-------	2,200	110	trace	92	97	760	22	345	58	(j)
-------	-------	-------	680	110	trace	29	26	140	trace	240	9.4	(k)
-------	-------	-------	4,200	140	trace	640	110	670	-------	-------	1,400	(l)
-------	-------	-------	600	110	[a]2.4	59	34	56	nil	410	32	(m)
-------	-------	-------	690	78	[a]1.8	47.8	14	110	-------	-------	85	-------
-------	-------	-------	720	73	[a]1.8	41.7	14	130	-------	-------	91	-------
-------	-------	-------	770	74	[a]1.6	38.4	13	150	-------	-------	108	-------
-------	-------	-------	690	59	1.6	15.4	7.8	130	-------	-------	94	-------
<5	245	4.6	370	72	1.4	41	120	6.1	nil	300	23	-------
-------	-------	-------	280	16	[a]2.5	87.3	2.1	9.2	-------	-------	nil	-------
-------	-------	-------	250	20	[a]1.2	76.6	11	4.9	-------	-------	10	-------
-------	-------	-------	350	13.5	[a]0.4	42.9	22	10	-------	-------	7.2	-------
-------	-------	-------	270	40	trace	59.4	5.1	13	-------	-------	9.1	-------
-------	195	-------	310	22.5	trace	96.5	11	12	nil	340	45	-------
nil	380	-------	550	15	trace	148	14	32	nil	460	nil	-------
50.0	17.0	nil	2,400	24	0.72	150	trace	1,000	13	nil	110	-------
-------	-------	-------	240	-------	-------	-------	-------	5.4	-------	-------	-------	-------
nil	300	16.0	531	18	0.52	63.4	27.5	110	nil	370	25	-------
-------	-------	-------	224	98	[a]1.2	18.76	5.5	4.9	nil	115	4.2	(n)
-------	-------	-------	-------	28	1	90.33	35	17	nil	370	42	(o)
-------	-------	-------	300	14.0	[a]1.2	50	3.4	21	-------	-------	21	-------
-------	-------	-------	-------	19	[a]0.37	64.5	26.72	27	nil	300	21	(p)
-------	-------	-------	390	24.5	1.3	92	10	-------	-------	-------	4	-------
nil	235	-------	315	15	trace	110	5.9	9	nil	287	trace	-------
-------	-------	-------	390	25	[a]0.8	92.8	11	4.5	-------	-------	3	-------
-------	-------	-------	-------	96	[a]2.6	80	64	120	-------	290	230	(q)
-------	-------	-------	-------	98.0	[a]1.4	80	68	120	nil	294	240	(r)
-------	-------	-------	-------	36	[a]1.1	59	40	64.5	nil	338	29.5	(s)

[i] Sodium (Na), 420.
[j] Sodium (Na), 485.
[k] Sodium (Na), 140.
[l] Potassium (K), 54; sodium (Na), 520; lithium (Li), 0.86.
[m] Potassium (K), 9.2; sodium (Na), 86.
[n] Phosphoric acid (PO_4), 1.6; potassium (K), 6.6; sodium (Na), 17.
[o] Phosphoric acid (PO_4), trace; potassium (K), 2.1.
[p] Iodine (I), trace; potassium (K), 2.8; sodium (Na), 29.
[q] Phosphoric acid (PO_4), trace; potassium (K), 8.5; sodium (Na), 150.5.
[r] Bromine (Br), trace; potassium (K), 6.7; sodium (Na), 150; strontium (Sr), 4.0.
[s] Iodine (I), trace; potassium (K), 6.0; sodium (Na), 65.

TABLE XII.—*Spring waters of*

Laboratory No.	Year.	Location. (Province, town, barrio.)	Source.	Temperature.
				°C.
	1910	Cebu, Oslob, Mainit	Spring B	35.8
	1910	do	Spring C	29.9
	1910	Cebu, Sibonga, Kanaga	North	33.0
	1910	do	South	32.5
	1910	Cebu, Toledo, Kambang-og		
123969-1	1917	Guam	Agat	
123969-2	1917	do	Asan	
123969-3	1917	do	Agana	
123969-4	1917	do	Fonte Dam	
123969-5	1917	do		
118260	1914	Ilocos Sur, Bantay, Paing	Canyau	
117934	1913	Ilocos Sur, Danglas	Hot	hot
111156	1913	Ilocos Sur, Vigan	Naguiddayan	
98446	1912	do	do	
123955	1917	Ilocos Norte, Vintar	Bisaya spring	
78433	1910	Iloilo, Guimaras		
121644	1915	Jolo, Jolo	Candasulig	34.0
51255	1907	Laguna, Los Baños	Isuan	
93063	1911	Laguna, Biñang		
123300	1916	Laguna, Los Baños	Hot	70.5
77156	1910	Laguna, Mabitac	Galas	
113260	1913	Laguna, Majayjay, Oobi	Sinabac	
27577	1906	Laguna, Pagsanjan		
120335	1915	Laguna, Pansol		
97081	1912	Laguna, San Pablo		
117796	1913	Leyte, San Isidro	Villahermosa	
117427	1913	Misamis, Agusan, Hibong	Aspeitia	
122293	1916	Misamis, Cagayan	Pigbalatojan	
123779	1916	do		
116154	1913	Misamis, Catarman	Coot	
44865	1907	Mindoro, Bulalacao, Mansatay		
119066	1914	Mindoro, Calapan		
118570	1914	Mindoro, Puerto Galera	Hot	very hot
124780	1917	Mountain, Daklan	Lower	
99591	1912	Mountain, Baguio, Camp John Hay		
104286	1912	Mountain, Baguio	Hospital Hill	
101638	1912	do	Antamok River	
90174	1911	do	Klondike's	
124780	1917	Mountain, Buguias		
124218	1917	Mountain, Cervantes	Abra River	hot
124218	1917	do	Comillas	
98796	1912	Mountain, Baguio	Pakdal	

[t] Potassium (K), 5.8; sodium (Na), 64; iodine (I), trace.

[u] Potassium (K), 4.0; sodium (Na), 27.

[v] Phosphoric acid (PO_4), trace; sodium (Na), 29; potassium (K), 5.4; metaboric acid (BO_2), present.

[w] Phosphoric acid (PO_4), trace; potassium (K), 5.4; sodium (Na), 3.0; strontium (Sr), 2.3; metaboric acid (BO_2), present.

[x] Phosphoric acid (PO_4), arsenic acid (AsO_4), trace; metaboric acid (BO_2), present; potassium (K), 3.4; sodium (Na), 180.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Miscellaneous.
------	------	------	------	32	[a]1.4	51	40	67	nil	337	29	(t)
------	------	------	------	40	[a]1	60	50	29	nil	342	24	(u)
------	------	------	------	23	[a]1.6	69	42	25	------	350	22	(v)
------	------	------	------	21	[a]3.9	70	37	30	nil	361	28	(w)
------	------	------	------	22	[a]2.7	60	21	125	------	270	180	(x)
4.4	170	9.2	200	trace	0.14	77	2.1	14	nil	210	trace	------
3.4	150	4.6	190	trace	0.14	70	3.1	15	nil	190	trace	------
10	230	19	510	8.0	0.28	100	6.6	110	nil	280	13	------
23	76	10.0	140	8.0	1.9	6.1	7.5	11	nil	90	nil	------
4.6	160	nil	210	8.0	0.44	54	1.6	15	nil	200	nil	------
------	------	------	180	32	[a]0.7	39	7.4	8.2	------	------	7.3	------
------	------	------	2,100	130	[a]19	160	6.5	280	nil	21	965	(y)
------	------	------	270	45	[a]2	66	9.8	4.75	------	------	trace	------
------	------	------	220	46	[a]1	44	7.1	4.4	------	------	11	------
------	180	nil	250	58	0.18	11	3.7	3.5	21	180	trace	------
------	------	------	260	6.7	[a]0.5	69	3.8	8.8	nil	342	4.3	(z)
------	85	------	150	59.5	0.25	12	9	7.2	nil	108	trace	------
------	------	------	------	160	[a]1.2	90	19	370	------	190	27	------
------	------	------	315	71	[a]0.4	38	13	16	------	------	17.5	------
<5	220	18.0	1,400	220	0.18	40	15	500	nil	270	30	------
------	------	------	880	93	[a]1.8	81	33	360	nil	319	22	------
------	------	------	100	------	------	------	------	2.9	------	------	------	------
------	------	------	290	------	------	------	------	18	------	------	------	------
nil	210	------	850	185	trace	39	20	250	10	260	37	------
------	------	------	210	35	[a]1.3	61	5.1	12	------	------	22	------
------	------	------	435	22	trace	94	14	46	------	390	11	(aa)
------	------	------	------	47.5	[a]11	1,200	4.4	7,200	------	------	460	(bb)
nil	320	32.2	780	27	0.20	99	93	7.6	------	395	trace	------
5.0	350	37.0	370	36.0	0.16	98	20	6.1	nil	430	trace	------
------	------	------	350	110	[a]1.7	51.1	16	4.4	nil	270	trace	(cc)
------	------	------	480	------	------	------	------	38	------	------	------	------
------	------	------	490	72	[a]1.7	87	8.7	56	------	------	6.5	------
------	------	------	------	80	------	170	220	520	38	980	580	(dd)
5,600	------	2,900	4,600	400	450	32	40	420	------	------	3,000	------
------	------	------	63	17	2.2	3.6	2.8	trace	------	------	56	------
------	------	------	310	------	------	------	------	2.9	------	------	------	------
------	------	------	------	185	[a]13	475	61	990	nil	490	425	(ee)
------	------	------	------	41	trace	130	trace	590	nil	21	350	(ff)
55	530	33	11,000	130	0.70	400	90	5,000	nil	640	53	------
60	82	10	1,700	100	0.6	180	4.6	400	nil	100	570	------
5	58	2.3	1,100	45	0.14	72	3	360	nil	70	200	------
------	------	------	92	------	------	------	------	trace	------	------	------	------

[y] Phosphoric acid (PO_4), 14; sodium (Na), 390; potassium (K), 84.

[z] Manganese (Mn), potassium (K), trace; sodium (Na), 5.0.

[aa] Potassium (K), 2.8; sodium (Na), 53.

[bb] Potassium (K), 16; sodium (Na), 3,650.

[cc] Phosphoric acid (PO_4), 1.04; potassium (K), 6.9; sodium (Na), 22.

[dd] Potassium (K), 355; sodium (Na), 2,900.

[ee] Potassium (K), 42; sodium (Na), 630.

[ff] Phosphoric acid (PO_4), potassium (K), trace; sodium (Na), 390.

TABLE XII.—*Spring waters of*

Laboratory No.	Year.	Location. (Province, town, barrio.)	Source.	Temperature.
				°C.
124462	1917	Mountain, Itogon		
124462	1917	Mountain, Kiangan		
118663	1914	Mountain, Mainit	Salt hot spring	hot
1085	1903	Nueva Vizcaya, Dopol	Saline springs	
124779	1917	Nueva Vizcaya, Oriong	Spring	
124780	1917	Nueva Vizcaya, Salinas	do	
115164	1913	Occidental Negros, Mambucal		39
115164	1913	do		39
115260	1913	do	Medicinal	
119824	1915	Oriental Negros, Tanjay	Mainit	hot
112523	1913	Pangasinan, Mount Balungao		
78654	1910	Rizal, Antipolo	Mabolo	
78655	1910	do	Bocal ng Tandang Yang.	
78656	1910	do	De la Virgen	
78657	1910	do	Marurunong	
81824	1910	Rizal, Malabon, San Bartolome	Near church	
119905	1915	Rizal, Pasig, Bagong-Ilog	Matang Tubig	
102294	1912	Rizal, Santa Inez	Mount Cailapa	
75529	1910	Rizal, Tanay		
60638	1908	Samar, Catbalogan	Naval hot	
60637	1908	do	Villahermosa	hot
120033-1	1915	Tayabas, Lucban	Pagsipi	
120439	1915	Tayabas, Mount Banahao		
115733	1913	Tayabas, Gasang Malbog	Mineral	
119406	1914	Tayabas, Guinayangan, Maulauin		
116187		Tayabas, Sariaya		
19608	1905	Tayabas, Tayabas	Laurente	
19608	1905	do	Taliong	
120044	1915	do	Lalo	
121249	1915	Tayabas, Tayabas, Silangan Palale	Mainit	48
116421	1913	Coron, Uson Island (?)		

[gg] Potassium oxide (K_2O), 23; sodium oxide (Na_2O), 460.

[hh] Phosphoric acid (PO_4), metaboric acid (BO_2), trace; potassium (K), 14; sodium (Na), 10.

[ii] Phosphoric acid (PO_4), 0.71; potassium (K), 15; sodium (Na), 50; metaboric acid (BO_2), trace.

[jj] Sodium (Na), 9.6; potassium (K), metaboric acid (BO_2), trace.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Miscellaneous.
120	370	nil	2,400	190	13	180	26	650	21	410	350	------
10	260	30	520	44	0.2	130	19	6	nil	320	105	------
------	------	------	------	195	[a]88	91	0.66	750	210	------	295	(gg)
------	------	------	40	110	------	280	140	22,000	------	------	------	------
90	340	nil	390	60	0.60	54	37	8	28	360	trace	------
800	1,800	65	40,000	110	1.8	900	220	20,000	nil	2,200	900	------
------	------	------	460	135	trace	57.5	21	8	nil	390	11	(hh)
------	------	------	465	170	trace	41	14	21	------	320	11	(ii)
------	------	------	340	9.2	trace	60	4.1	8.9	------	380	6.1	(jj)
------	------	------	6,400	44.5	trace	210	150	2,700	nil	230	260	------
------	------	------	26,000	35	trace	5,100	little	15,000	nil	23	710	(kk)
------	------	------	240	------	------	------	------	2.8	------	------	------	------
------	------	------	230	------	------	------	------	2.3	------	------	------	------
------	------	------	290	------	------	------	------	21	------	------	------	------
------	------	------	170	------	------	------	------	1.9	------	------	------	------
------	------	------	470	------	------	------	------	53.5	------	------	------	------
------	145	------	250	70	nil	25	9.8	38	nil	180	nil	------
------	------	------	250	------	------	------	------	------	------	------	------	------
------	------	------	------	100	trace	34	11	2.3	------	180	2.8	(ll)
------	------	------	750	------	------	------	------	29	------	------	------	------
------	------	------	450	------	------	------	------	54	------	------	------	------
------	54	------	140	62	0.7	5.4	5	5.1	trace	65	nil	------
------	------	------	105	50	trace	11	3.9	6	nil	49	nil	------
------	------	------	1,200	72	[a]2.4	260	48	110	nil	940	87	(mm)
------	260	------	330	4	trace	86	11	22	nil	320	14	------
------	------	------	110	75	4.0	3.7	1.5	2.5	------	------	trace	------
------	------	------	120	------	------	------	------	7	------	------	------	------
------	------	------	100	------	------	------	------	7	------	------	------	------
------	43	------	100	57.5	1.6	8	4	5.2	nil	52	4.1	------
------	37.5	------	1,800	------	------	------	------	890	32	6.1	------	------
------	------	------	57	17	[a]3.6	2	2.1	10	------	------	------	------

[kk] Metaboric acid (BO_2), bromine (Br), iodine (I), present; manganese (Mn), trace; potassium (K), 26; sodium (Na), 4,200.

[ll] Potassium (K), 3.5; sodium (Na), 16; metaboric acid (BO_2), 1.2; alumina (Al_2O_3), trace.

[mm] Phosphoric acid (PO_4), lithium (Li), trace; potassium (K), 22; sodium (Na), 101.

TABLE XIII.—*Surface waters of the Philippine Islands.*

Laboratory No.	Year.	Location. (Province, town, barrio.)	Source.	Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorides (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
82704	1910	Batangas, Lipa, Talisay					240	100	2.8	19	5.8				trace
84441	1910	Batangas, Taal	Pansipit River				1,500	7.8	1.4	49	49	620			180
123959	1917	do	Taal Lake		160	nil	1,900	56.0	0.36	70.0	58.0	660.0	14	170.0	260.0
94257	1911	Bohol, Davis, Dao	Surface well				330	11.2	trace	110	1.5	21			15
86655	1911	Bohol, Tagbilaran, Luncayab	do				400					53			
86656	1911	Bohol, Tagbilaran, Mansasa	do				1,200					440			
93941	1911	Bohol, Tagbilaran, Cogon	Well				430	1.2	12	120	2.0	150			29.0
97173	1912	Bulacan, San Miguel de Mayumo.	Sibul estero				300	21.0	2.0	97	1.9	17			0.98
97174	1912	do	Canal Sibul				410	20	2.3	120	12	34			16
87656	1911	Capiz, Capiz, Tabuc	Surface well				1,700	22	1.4	94.0	63	720			130
117473	1913	Cebu, Cebu	Engayo well				460					27			
117477	1913	do	Dug well				405					5.9			
121876	1916	do	Osmeña Water Works	nil	190	nil	365	34	0.84	77.0	17.0	6.1	nil	240	82.3
94003-1	1911	Cebu	High fall, Lajog Creek				220	47	trace	40	8.4	6.4			trace
94003-2	1911	do	1.2 kms. above falls				210	34	trace	42	10	22.5			trace
94003-3	1911	do	Near head of Lajog Creek				175	26	trace	43	5.6	7.3			trace
94003-4	1911	do	Guadalupe Creek				245	41	trace	36	16	13			trace
36976	1906	Cebu, Cebu, at highway bridge.	Guadalupe River				845	36	1.7	150	22				49.3
120289-1	1915	Cebu	Cavern west of mill	nil	225		540	10	trace	98	13.0	135	trace	270	18.5
120289-2	1915	do	Well at tunnel	nil	170		275	17.5	trace	79	3.2	50	trace	210	trace
120289-3	1915	do	Water supply, Pajo	nil	240		590	10	trace	130	6.5	125	trace	290	14.5
120289-4	1915	do	Well	nil	210		895	32.5	trace	120	17	300	trace	260	26.8
37929	1906	Cebu, Danao, poblacion	Danao River				5,000	20	1.2	160	45				330

119540	1914	Cebu, Mactan	Surface well	(a)	215		4,200	10.0	1.2	350	150	1,900	nil	260	200
119651	1915	do	do		250		400	10.0	1.2	100	3.8	37	nil	300	4.1
119683	1915	do	Well	(a)	200		370	12.5	1.2	110	1.1	20	nil	240	nil
120973-1	1915	Cebu, Mactan, Pajo bridge		nil	225		875	5.0	1.2	129	20	260	nil	270	29
120973-2	1915	Cebu, Mactan	Twin wells, connected by a tunnel.	nil	230		385	2.5	1.2	100	2.6	45	nil	280	6.2
121552	1915	Cebu, Obon	Well		280	19	400	29.0	0.5	180	20.0	7.2	nil	330.0	trace
86659	1909	Iloilo, Jaro	Jaro River				320	22	1.2	43.0	8.4				2.8
68658	1009	Iloilo, Passi	Passi well				640	92	3.2	68	19				13
68657	1909	Iloilo, Pototan	Pototan River				300	23	0.8	53	8.7				3.9
122705	1916	Jolo, Jolo	Legian stream	25	65		100	32	0.48	little	7.9	4.2	nil	79	trace
118709	1914	Jolo	Sablay Puti River			4.6	210					4.3			
118708	1914	do	Taigkasan River				200					5.1			
93063-1	1911	Laguna, Biñang	Open well				650	61-	1.2	100	31.0	57			71
93063-2	1911	do	Open well, back of cockpit.				530	76	0.2	84	24	78			55
93063-3	1911	do	Open well, center of poblacion.				810	73	1.0	110	33	89			70
112148	1913	Laguna, Calamba	Well				320	90	3.2	34.0	16	3.5			little
67953	1909	Laguna, Santa Rosa	Stream, poblacion				410	87	2.0	66	16	4.9		370	2.4
118304	1914	Manila	City water				150	24	1.7	31	6.5	4.1	nil	140	14
123860-1	1916	Manila, Jones Bridge	Pasig River, surface, high tide.	60	70	nil	760	36	2.8	17	28	310	nil	85.0	40
123860-2	1916	do	Pasig River, ½ from bottom, high tide.	95	110	nil	31,000	10	0.80	320	1,100	15,000	9.6	110	1,500
123860-3	1916	do	Pasig River, ½ from bottom, low tide.	90	76	nil	8,100	69	1.0	100	250	3,800	3.4	85.0	380.0
123860-4	1916	do	Pasig river, surface, low tide.	70	70	nil	780	18	0.88	2.8	6	120	nil	85.0	5.4
26700	1905	Manila, Santa Ana	Driven well				1,000					220			
121129	1915	Misamis, Balingasag	Lagamit River		59		150	45	0.2	24	7.8	4.6	nil	72	29
	1911	Mountain; near Kiangan	Deep lake				74	24	5.0	6.0	2.8	little			3.1

[a] Turbid; turbidity not determined quantitatively.

TABLE XIII.—*Surface waters of the Philippine Islands*—Continued.

Laboratory No.	Year.	Location. (Province, town, barrio.)	Source.	Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorides (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
117885	1913	Mountain, Baguio, Hotel Pines.	Artificial lake				730	61	4.8	21.5	11	160			nil
124387	1917	Nueva Ecija, Cabanatuan, pine land.	Surface well	20	170	19.0	230.0	55	2.4	32	11.0	5.2	nil	200.0	trace
114362	1913	Nueva Ecija, Cabanatuan, plain field.	Well				250.0			little	9.4	3.3			
123064	1916	Nueva Ecija, Muños	Surface well	(a)	200.0	40.0	2,400						nil	345	
95187	1911	Oriental Negros, Dumaguete	Maite River, surface				220					6			
95188	1911	do	Maite River, bottom				220					11			
95189	1911	do	Maite River, side surface				220					11			
95194	1911	do	Dumaguete River, surface.				160					8.4			
95195	1911	do	Dumaguete River, bottom.	(a)			220					12.8			
95196	1911	do	Dumaguete River, side surface.	(a)			165					7.1			
122857	1916	Pampanga	Rio Grande		100	nil	160	39	4.4	18.0	4.0	7.0	nil	120.0	5.0
88271	1911	Pangasinan	Rio Agno				210	31	2.2	37	5.0	12			62
120358	1915	Pangasinan, Bani	Bani River	nil	130		140	25	trace	50.0	1.6	9.0	trace	160	trace
118446	1914	Palawan	Underground river				8,700	24	3.7	140	310	5,600			620
	1911	Rizal, Pasay	Open well, side of cockpit.				890	54	trace	160	44	130			87
	1911	Rizal, Pasay, Calle Burgos	Open well				1,200	44	trace	155	55	140			148
	1911	Rizal, Pasay, No. 3 Calle Dominga.	do				790	20	trace	140	35	89			69

122519	1916	Rizal, Pasay, behind Polo Club.	do	5.0	200	nil	270	85.0	0.16	53	14.2	14	nil	250	5.1
118065	1914	Rizal, San Juan del Monte	do				260	120	4.9	20	7.5	7.6			trace
22195	1905	Samar, Laguilocan	Stream				290					8.5			
60636	1908	Samar, Catbalogan	Palo River				130					4.95			
60635	1908	do	Tibac Creek				240					3.4			
124914	1917	Tayabas, Gumaca	River	85.0	190	7.0	19,000	11	0.72	260	700.0	9,100	nil	240	1,100
118179	1914	Tayabas, Lucena	Macaas River				140					6.4			
117944	1913	Tayabas, Lucena, poblacion	Surface well				530					27			
76846-1	1910	Tayabas, Malanay	Puting cahoy, surface well.				500			80		28			
76846-2	1910	do	Surface well				500			115		18			
76846-3	1910	do	do				560			120		44			
19608-1	1905	Tayabas, Tayabas	Alitaw River				160					trace			
19608-2	1905	do	Bamban Grande				150					trace			
19608-3	1905	do	Munting Bayan				370					58.0			
122294	1916	Zamboanga, Zamboanga	Tumaga River		99.5		130	25	0.2	30	5.9	3.8		210	9.6

[a] Turbid; turbidity not determined quantitatively.

TABLE XIV.—*Surface waters of the Philippine Islands.*

WELLS.

Location. (Province, town, barrio.)	Year.	Depth.	Temperature.	Turbidity.	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Iron (Fe).	Chlorides (Cl).	Normal carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Total hardness ($CaCO_3$).	Estimated incrustants.	Classification for boiler use.	Colonies per cubic centimeter.	Presumptive test.
		m.	°*C.*													
Cebu, Alcantara, poblacion	1916		28.0	69	420	37	0.4	290	nil	510	85	475	510	Bad	67,000	Positive.
Cebu, Alegria, poblacion	1916	4.0	28.5	trace	460	13	5.1	350	nil	560	110	560	600	do		
Cebu, Aloguinsan, poblacion	1916		29.0	trace	520	23	0.03	180	nil	630	41	470	520	do	18,000	Do.
Cebu, Badian, poblacion	1916	5.0	24.5	nil	290	15	5.0	12	nil	350	trace	230	260	Poor	2,600	Negative.
Cebu, Barili, poblacion	1916			nil	450	34	0.4	81	nil	550	120	430	520	Bad		
Cebu, Dumanjug, poblacion	1916	3.0	29.5	nil	320	7.6	2.2	26	nil	390	30	240	300	Poor	3,800	Positive.
Cebu, Ginatilan, poblacion	1916		28.0	nil	480	14	0.07	67	nil	586	110	600	610	Bad	2,800	Do.
Cebu, Malabuyoc, poblacion	1916		28.0	nil	410	trace	1.25	160	nil	500	190	470	570	do	4,800	Do.
Cebu, Moalbual, poblacion	1916		29.0	nil	410	18	0.07	530	nil	500	130	475	540	do		
Cebu, Ronda, poblacion	1916	2.2	28.5	trace	410	24	0.2	67	nil	500	77	350	430	do	25,000	Do.
Laguna, Calamba, poblacion	1916			nil	200	35	0.07	12	nil	240	18	130	180	Fair	many	Do.
Laguna, Los Baños, poblacion	1916		41.0	nil	260	23	0.2	410	nil	320	67	280	330	Poor		
Laguna, Pagsanjan	1916	3.0	33.5	nil	175	nil	nil	29	trace	210	20	44			13	Negative.
Do	1916	9.1	28.5	nil	150		0.5	68	nil	187	25	100			70	Positive.
Laguna, Santa Cruz	1916		26.3	nil	170	nil	0.25	30	17.0	180	34	125				
Laguna, Santa Cruz, Gatid	1916		28.0	nil	170	47	0.25	15	nil	210	13	120			2,100	Do.
Misamis, Cagayan, poblacion	1916		27.0	trace	33	32	6.0	8.6	nil	40	300	580	310	Poor		
Occidental Negros, Hinigaran, poblacion.	1917	6.0	29.2	trace	360	20	1.2	15	nil	440	14				15	Negative.
Occidental Negros, Isabela, poblacion.	1917	5.0	26.8	nil	150	38	0.53	7.5	nil	180	8				12,000	Positive.

Occidental Negros, La Carlota, San Antonio, hacienda.	1917	......	26.0	trace	80	56	0.53	38	nil	98	trace	150	115	Fair	18,000	Do.
Occidental Negros, Talisay, poblacion.	1917	......	26.7	nil	195	41	0.58	230	nil	240	100	......	......	......	......	
Occidental Negros, Victorias, poblacion.	1917	7.5	27.0	trace	20	29	0.2	7.0	nil	24	trace	......	......	Good	3,000	Do.
Rizal, Mariquina, poblacion	1916	......	27.5	nil	310	45	0.1	85	nil	380	90	230	......	Poor	......	
Rizal, Pasig, poblacion	1916	9.0	30.0	nil	260	37	1.6	41	nil	320	31	120	220	do	......	
Do	1916	......	27.0	nil	260	26	0.03	96	nil	320	41	140	240	do	......	
Rizal, San Mateo, poblacion	1916	6.5	28.0	nil	500	59	0.08	49	nil	610	100	180	430	Bad	......	
Rizal, Taytay, Calle Morga	1916	......	28.0	nil	290	42	0.12	110	nil	350	90	160	300	Poor	88,000	Do.
Sorsogon, Donsol	1916	......	27.5	nil	360	32	0.2	44	nil	440	17	220	300	do	6,000	Do.
STREAMS.																
Laguna, Bay	1916	......	......	80	220	9.0	0.5	27.0	nil	270	31	140	210	Poor	......	
Laguna, Calamba, poblacion	1916	......	34.0	trace	160	8.3	0.88	6.0	nil	195	18	96	140	Fair	......	
Laguna, Calamba	1916	......	31.0	210	90	nil	0.73	83.0	15.0	93	trace	50	70	(a)	......	
Laguna, Los Baños, Mount Maquiling.	1916	......	25.0	trace	41	5.0	0.25	9.0	nil	50	28	44	......	......	525	Do.
Laguna, Los Baños, College of Agriculture.	1916	......	25.5	......	......	......	......	......	......	......	......	......	......	......	350	Do.
Laguna, Paete, town	1916	......	26.5	nil	190	13.0	0.4	8.8	nil	140	trace	90	......	......	......	
Laguna, Pagsanjan, town	1916	......	29.0	trace	66	......	0.67	10	nil	80	trace	41	......	Fair	......	
Laguna, Santa Cruz, town	1916	......	28.5	(a)	110	trace	1.3	12	nil	130	nil	70	......	......	......	
Misamis, Cagayan, poblacion	1916	......	23.8	55	50	<2.0	1.5	<2.0	nil	67	trace	56	53	Good	355	Do.
Occidental Negros, La Carlota, Canlaon, hacienda.	1917	......	26.0	90	73	<2.5	0.83	2.5	nil	89	trace	84	80	do	......	
Occidental Negros, La Carlota, Isabel, hacienda.	1917	......	24.5	48	68	4.0	0.47	5.0	nil	77	20	110	120	Fair	......	
Occidental Negros, La Carlota, San Antonio, hacienda.	1917	......	24.0	trace	51	2.5	0.27	4.4	nil	62	48	120	130	do	......	
Rizal, Mariquina, Santa Elena	1916	......	28.6	trace	110	10.0	1.0	6.0	nil	130	trace	75	190	do	......	

[a] Good after sedimentation.

TABLE XIV.—*Surface waters of the Philippine Islands*—Continued.

STREAMS—Continued.

Location. (Province, town, barrio.)	Year.	Depth.	Temperature.	Turbidity.	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Iron (Fe).	Chlorides (Cl).	Normal carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Total hardness ($CaCO_3$).	Estimated incrustants.	Classification for boiler use.	Colonies per cubic centimeter.	Presumptive test.
		m.	°*C.*													
Rizal, Montalban	1916		29.7		170			6.0	nil	210	trace	85	130	Fair	150	Positive.
Rizal, Pasig	1916		31.5	(b)	200	<5.0			nil	240	trace	82	140	do		
Do	1916		31.4	trace	96	5.0	0.9	48.0	nil	120	trace	50	73	Good	30,000	Do.
Sorsogon, Bacon	1916		25.2	trace	120	trace	0.6	10.0	nil	150	16	86	120	Fair		
Sorsogon, Bulusan	1916		24.7	nil	56	trace	trace	10.0	nil	68	18	41	61	Good	555	Do.
Sorsogon, Sorsogon, Guinlajon	1916		24.0	trace	41	trace	0.2	10.0	nil	50	49	56	88	do	700	Do.
Do	1916		24.0	trace	44	trace	0.23	11.0	nil	54	50	63	89		135	Do.
Do	1916		22.6	nil	40	trace	0.3	10.0	nil	49	43	59	80	Good	145	Do.

[b] Turbid; turbidity not quantitatively determined.

TABLE XV.—*Well waters*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
11705	550	1913	Albay, Albay	85.3	P 45	
122307	809	1916	Albay, Bacacay	99.7	F 23	nil
119419	680	1914	Albay, Bato, Cabugao	42.7	P 49	
123067	953	1916	Albay, Camalig	50.2	P 379	<5
123123	968	1916	do	38.1	F 68	<5
121784	849	1916	Albay, Guinobatan	145.3	P 303	nil
121866	881	1916	do	47.2	P 151	nil
112669	494	1913	Albay, Ligao	91	F 38	
122069	890	1916	do	96.0	F 57	nil
118001	578	1913	Albay, Malinao	114	F 170	
124395	1004	1917	Albay, Malilipot	56.4	F 227	nil
115366	505	1913	Albay, Oas	152	P 284	([a])
123066	944	1916	do	61.0	P 76	<5
122138	904	1916	Albay, Polangui	57.9	F 57	5
122321	912	1916	do	25.9	P 568	nil
122492	929	1916	do	57.9	F 87	3.0
122577	932	1916	do	47.2	P 379	2.0
118685	601	1914	Albay, Tabaco	121.9	F 57	
119990	717	1915	do	147.8	F 114	([a])
123394	971	1916	do	112.8	F 114	7.0
123739	990	1916	do	103.5	F 416	nil
125020	1032	1917	do	48.7	F 38	nil
124762	1017	1917	do	107.3	F 76	10.0
120565	777	1915	Albay, Tiwi	102.4	F 38	([a])
118656	615	1914	Albay, Virac	265.8	P 23	
118814	648	1914	do	59.4	P 681	
119202	657	1914	Albay, Virac, Calatagan	235.9	P 61	
71804	118	1909	Ambos Camarines, Nueva Caceres	11	P 189	
74040	129	1909	do	58	P 151	
119112	443	1914	Ambos Camarines, San Jose	37	P 68	
97406	(?)	1912	Ambos Camarines, Calle Dasmariñas ?			
119601-1		1914	Bataan, Orion, Calle Panganiban			
119601-2		1914	Bataan, Orion, Calle Real			
119601-3		1914	Bataan, Orion, Calle Tangaran, Plaza P. Gomez.			
119601-4		1914	Bataan, Orion, Calle Bagumbayan, Plaza P. Gomez.			
117935-1		1913	Bataan, Pilar, Calle San Pedro			
117935-2		1913	Bataan, Pilar, Calle Mabolo, Sta. Rosa			
117935-3		1913	Bataan, Pilar, Calle Masantol, Sta. Rosa			
117935-4		1913	Bataan, Pilar, Calle San Jose			
117935-5		1913	Bataan, Pilar, Calle San Pedro			
117935-6		1913	Bataan, Pilar, Bataan Pequeña, Calle San Jose.			
117935-7		1913	Bataan, Pilar, Calle Kansas			
117935-8		1913	Bataan, Pilar, Sta. Rosa (Luwasan)			
117462	507	1913	Batangas, Alitagtag	113	P 189	
78712	164	1910	Batangas, Balayan	114	F 227	

[a] Yellow.

of the Philippine Islands.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
--------	--------	--------	1,800	64	3.6	23	trace	960	--------	--------	33
160	2,200	160	3,700	71	1.0	83	60	700	--------	2,600	180
slight	120	--------	1,600	30	trace	36	6.3	570	nil	145	43
15	195	14	460	85	0.8	47	22	26	nil	240	110
50	230	20	570	80	1.6	50	33	30	nil	280	140
high	165	190	1,800	74	13	210	240	36	--------	200	39.5
--------	160	9	445	77	0.6	55	18	18	nil	190	100
--------	--------	--------	450	62	2.0	20	11	32	--------	--------	trace
35	340	5.3	460	69	0.68	18	10	29	nil	420	trace
--------	--------	--------	990	67	trace	51.5	43	218	--------	--------	95
5	150	4.6	220	60	0.60	7.5	17	11	nil	180	nil
--------	--------	--------	605	68	3.6	11	10	107	--------	--------	trace
40	330	18	940	54	1.5	50.0	19	275	nil	415	trace
53	520	32	620	80	2.8	78.0	38	43	nil	640	trace
5	350	27	460	73	2.4	76	24	7.6	--------	431	trace
55	520	22	580	76	1.0	77	32	29	--------	630	trace
32	580	23	710	50	1.2	73	40	62	nil	710	trace
--------	--------	--------	210	60	3.7	1.2	nil	6.2	--------	--------	88
(b)	245	--------	570	65	0.5	8.9	12	85	nil	300	trace
--------	160	4.6	300	70	0.38	2.2	<2.0	12	nil	200	trace
<5	90	nil	140	60	0.20	5.1	1.4	4.4	nil	110	trace
20	70	10.0	210	105	0.06	9.7	1.6	5.5	nil	80	--------
nil	120	nil	250	90	0.24	trace	trace	7.2	nil	150	trace
(b)	370	--------	1,100	150	trace	7.0	8.7	190	nil	450	120
--------	--------	--------	420	--------	--------	--------	--------	7.6	--------	--------	--------
--------	--------	--------	670	26	1.7	37	30	191	--------	--------	44
--------	--------	--------	560	22	1.7	64	31	130	--------	--------	24
--------	--------	--------	390	--------	--------	--------	--------	18	--------	--------	--------
--------	--------	--------	120		--------	--------	--------	6.3	--------	--------	--------
high	--------	--------	290	86	7.7	31	3.4	4.3	--------	--------	92
--------	--------	--------	490	--------	--------	--------	--------	150	--------	--------	--------
nil	130	--------	235	90	trace	25	11	6.2	nil	160	trace
nil	140	--------	235	85	trace	25	11	8.2	nil	170	trace
nil	140	--------	235	90	trace	22	11	6.2	nil	160	trace
nil	130	--------	235	90	trace	22	12	6.2	nil	160	trace
--------	--------	--------	290	98	2.5	16	60.3	12	--------	--------	trace
(b)	--------	--------	270	--------	--------	--------	--------	4.4	--------	--------	--------
--------	--------	--------	275	--------	--------	--------	--------	3.4	--------	--------	--------
--------	--------	--------	300	--------	--------	--------	--------	12	--------	--------	--------
--------	--------	--------	290	--------	--------	--------	--------	13	--------	--------	--------
--------	--------	--------	290	--------	--------	--------	--------	13	--------	--------	--------
--------	--------	--------	300	--------	--------	--------	--------	12	--------	--------	--------
--------	--------	--------	280	91	trace	27	14	2.5	--------	--------	trace
--------	--------	--------	380	74	4.8	43	8.9	4.4	--------	--------	trace
--------	--------	--------	395	93	2.8	53	15.5	7.4	--------	--------	--------

[d] Filtered.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
79221	175	1910	Batangas, Balayan	114	F 568	------
98447	354	1912	Batangas, Balayan, Calatagan	238	P 95	------
118046	584	1914	Batangas, Batangas	145.7	P 151	------
119051	670	1914	Batangas, Batangas, Calle Jaena	74	P 379	------
119111	673	1914	Batangas, Batangas, Plaza of Government Building.	77.7	P 379	------
119211	681	1914	Batangas	128.6	P 379	------
119293	686	1914	Batangas, Batangas, Calle P. Burgos	136	P 189	------
119420	690	1914	----do	128	P 114	------
119581	697	1914	----do	115.8	P 132	------
120551	785	1915	Batangas, Batangas, Paharang	65.5	P 95	------
120614	794	1915	Batangas, Batangas, Sampaga	67.6	P 114	------
120733	800	1915	----do	80.5	P 114	------
120831	804	1915	Batangas, Batangas, Tolo	87.1	P 114	------
121352	815	1915	Batangas, Batangas, Dumantay	67.3	P 114	------
121146	839	1915	----do	68.8	P 473	nil
121451	852	1915	Batangas, Batangas, Santa Rita	106	P 114	nil
121566	860	1915	Batangas, Batangas, Mahabang Parang	99.6	P 45	nil
68518	79	1909	Batangas, Bauan	80.7	P 303	------
113010	495	1913	----do	91	F 379	------
117608	499	1913	----do	125	P 76	------
117610	522	1913	----do	128.9	P 76	------
117444	555	1913	----do	152	P 303	(c)
117897	563	1913	----do	153	P 189	------
117898	571	1913	Batangas, Batangas, Lagnas	158	P 757	------
119134	638	1914	Batangas, Batangas, Asias	46.0	P 132	------
123402	982	1916	----do	79.2	P 38	nil
123759	997	1916	Batangas, Batangas, Cupang	68.3	P 30	------
124295	1000	1917	Batangas, Bauan	67.4	P 45	------
124667	1020	1917	Batangas, Bauan, Aloiam	94	P 45	nil
124511	1011	1917	Batangas, Bauan, Bulibay	82.9	P 45	nil
119073	640	1914	Batangas, Bolbok	142.9	F 19	(a)
119255	672	1914	----do	138.7	F 57	------
119564	688	1914	Batangas, Bolbok, Sico	179.8	F 76	------
122156	712	1916	Batangas, Bolbok, Quipot	236.2	P 76	nil
121282	780	1915	----do	132	P 114	------
121284	822	1915	Batangas, Bolbok, Talahiban	160	F 76	------
121351	846	1915	Batangas, Batangas, Bolbok	101.5	P 95	------
121837	847	1916	Batangas, Bolbok	172.2	F 114	6.0
122416	882	1916	----do	182	P 30	2.0
105125	420	1912	Batangas, Lipa	58	P 246	------
122690	942	1916	----do	43.3	P 45	nil
122771	946	1916	----do	37.5	P 45	nil
122889	952	1916	Batangas, Lipa, Antipolo	34.7	P 45	nil
122977	955	1916	Batangas, Lipa, Anilao	43.6	P 45	nil
123054	961	1916	----do	19.2	P 45	nil
123196	966	1916	----do	102.1	P 30	nil
124967	1031	1917	Batangas, Ibaan	47	P 38	nil

[a] Yellow.

[c] Brown.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
--------	--------	-------	380	81	3.6	40	15	8.5	--------	--------	--------
--------	--------	-------	1,300	63	3.2	15	4.7	455	--------	--------	41.6
(b)	--------	-------	330	59	1.7	43	16.6	4.7	--------	--------	9.2
--------	--------	-------	380	74	3.7	35.5	17	10	--------	--------	7.3
--------	--------	-------	390	78	3.7	28	18	9.2	--------	--------	11
--------	--------	-------	360	68	3.7	40	14	11.5	--------	--------	7.2
(b)	--------	-------	380	68	trace	15	15	9.9	--------	--------	7.2
nil	270	-------	370	6.5	trace	43	16	6.3	nil	190	43
nil	250	-------	360	57.5	trace	48	19	7.2	nil	280	4.1
nil	320	-------	515	90	trace	95	22	30	nil	390	nil
nil	225	-------	380	92	2.0	57	19	14	nil	270	nil
nil	245	-------	385	90	trace	77	22	10	nil	300	trace
nil	250	-------	400	100	3.0	52	22	10	nil	305	6.0
--------	255	-------	400	83	0.25	56	24	14	nil	310	trace
--------	260	-------	370	76.5	0.7	31	22	7.7	nil	320	8.2
--------	285	-------	420	74.5	1.1	50	22	9.3	nil	350	trace
--------	220	-------	370	100	0.7	39	13	8.2	--------	270	trace
--------	--------	-------	700	--------	--------	--------	--------	5.4	--------	--------	--------
--------	--------	-------	360	74	2.0	41	16	7.8	--------	--------	7.0
--------	--------	-------	370	79	2.8	46	15	8.5	--------	--------	3.6
(b)	--------	-------	420	73	4.8	39	17	7.0	--------	--------	6.4
--------	--------	-------	380	88	0.4	60	27	5.6	--------	--------	4.4
--------	--------	-------	380	81	trace	39	14.5	6.9	--------	--------	trace
--------	--------	-------	360	71	2.9	42	17	4.2	--------	--------	5.1
--------	--------	-------	390	76	7.7	50	11	13	--------	--------	100
60.0	250	7.0	400	95	1.2	45	15	8.4	nil	300	trace
<5.0	170	23	440	80	0.28	49	11	25	nil	190	<5.0
10.0	280	14	420	90	0.95	56	20	10	nil	340	trace
65.0	210	10	410	160	1.3	38	12	7.6	nil	260	3.0
60.0	380	11	530	90	0.80	90	28	10	nil	470	8.2
--------	--------	-------	860	32	3.7	1.2	1.2	166	--------	--------	nil
--------	--------	-------	980	38	3.7	18	11	250	--------	--------	12.1
slight	550	-------	825	32	2.5	10	nil	110	nil	650	nil
75.0	550	16	1,500	85	6.8	49	15	490	nil	670	trace
--------	505	-------	910	60	1.1	34	19	175	nil	620	trace
--------	540	-------	1,400	72.5	1.15	7.1	8.9	200	nil	660	trace
--------	240	-------	380	80	1.15	45	16	8.7	nil	290	trace
nil	510	13	920	37	1.3	14	9	160	nil	625	trace
85.0	520	5.4	1,400	68	1.8	29.5	28	440	--------	640	trace
--------	--------	-------	295	94	3.0	35	10	7.8	--------	--------	15
3.0	120	32	270	100	0.22	18	6.2	12	nil	150	5.9
10.0	160	35	320	80	0.22	35	16	16	nil	200	10.0
30.0	170	45	490	100	1.9	57	53	36	nil	210	18.0
<5.0	160	32	330	100	0.5	32	12	15	nil	200	7.8
nil	125	33	290	120	0.16	26	7.5	12	nil	150	trace
200	120	23	330	200	1.6	20	<5.0	7.3	nil	140	trace
250	170	13	300	85	0.18	26	11	11	nil	200	trace

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
125009	1050	1917	Batangas, Ibaan	32	P 38	nil
124929	1045	1917	Batangas, Ibaan, San Jose	41	P 38	nil
93292	307	1911	Batangas, Nasugbu		P 23, F 19	(a)
95430	339	1911	do	47	P 151	
122578	935	1916	Batangas, Rosario	59.1	P 45	nil
120438	779	1915	Batangas, San Isidro	48.8	P 114	(a)
119898	713	1915	Batangas, San Jose (plaza)	35.7	P 95	
119947	730	1915	Batangas, San Jose, Calle Burgos	36.6	P 95	
119984	736	1915	Batangas, San Jose, Calle Biacnabato	29.3	P 95	
120041	744	1915	Batangas, San Jose, Nomel	29.3	P 95	
115331		1913	Batangas, Santo Tomas			(a)
70173	92	1909	Batangas, Taal	189		
117463	529	1913	Batangas, Taal, Balisong	113	P 189	
123530	988	1916	do	30.5	P 30	nil
123618	995	1916	Batangas, Taal, Calumpang	90.5	P 30	nil
108462	436	1912	Batangas, Tanawan	337	P 189	(c)
109984	469	1912	do	128	P 189	
121739	873	1916	do	50	P 45	nil
87828		1911	Bohol, Albuquerque			
83743		1910	Bohol, Bacloyon, Laya			
81901		1910	do		P 61	
74636		1909	Bohol, Dimiao, near municipal building	10		
118223	577	1914	Bohol, Inabanga	130.1	P 38	
79477	3?	1910	Bohol, Loboc, Ilaya			
79478	2?	1910	do			
83330		1910	Bohol, Loboc, Sauang			
83331		1910	Bohol, Loboc, Villaflor			
117767	551	1913	Bohol, Loon	79.2	P 57	
96694		1912	Bohol, Panglao, Tagnan			
80289	167	1910	Bohol, Tagbilaran	171	P 227	
91226		1911	Bohol, Tagbilaran, Mansasa			
118408	192	1914	do	213	P 227	
118556	619	1914	do	28.7	P 379	
105141	400	1912	Bulacan, Angat	142	F 303	
85759	224	1911	Bulacan, Baliuag	152	F 95	
87524	246	1911	do	119	F 719	
89432	279	1911	do	163	F 57, P 114	
97049	345	1912	do	124	F 151	
98529	364	1912	do	130	F 47	
118047	586	1914	Bulacan, Baliuag, Camboag	157.3	F 114	
118305	603	1914	Bulacan, Baliuag, Tanauan	135.9	F 76	
118596	616	1914	Bulacan, Baliuag, Sabang	134.1	F 227	
47956		1907	Bulacan, Bigaa			
43533		1907	Bulacan, Bulacan			
105809		1912	do			
49775		1907	Bulacan, Bocaue	128		
78825	162	1910	Bulacan, Calumpit	124	F 64	
44052		1907	Bulacan, Guiguinto			

[a] Yellow. [c] Brown.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
nil	120	40	330	100	0.14	34	9.2	27	nil	150	nil
10.0	160	16	350	100	0.24	36	8.6	26	nil	200	trace
--------	--------	--------	640	120	4.0	4.7	2.16	58	--------	--------	68.0
--------	--------	--------	650	78.5	6.5	23	20	220	--------	--------	19
5.0	180	48	400	50	0.48	52	13	17	nil	220	20
high	320	--------	485	80	4.0	71.5	29	25	nil	390	4
(b)	150	--------	330	77.5	0.5	50	17.5	21	nil	180	16.5
nil	175	--------	300	77.5	nil	27	13	9.0	nil	210	12
nil	200	--------	365	80	trace	63	21	20	nil	240	14
--------	130	13	320	120	0.6	19	13	20	nil	130	12.5
(b)	--------	--------	270	--------	--------	--------	--------	6.9	--------	--------	--------
--------	--------	--------	5,100	--------	--------	--------	--------	2,600	--------	--------	--------
--------	--------	--------	490	--------	--------	--------	--------	25	--------	--------	--------
10.0	170	28	350	100	0.42	31	1.2	13	nil	230	8.5
95.0	140	28	370	200	0.68	18	3.0	8.8	nil	170	trace
(b)	--------	--------	325	72	6.0	36	7.6	12	--------	--------	57
(b)	--------	--------	280	84	3.8	25	6.7	9.4	--------	--------	32
nil	160	--------	340	90	0.4	39	10	1.6	nil	195	33
--------	--------	--------	330	--------	--------	--------	--------	7.8	--------	--------	--------
--------	--------	--------	1,500	13	0.5	170	121	590	--------	--------	295
--------	--------	--------	1,300	--------	--------	--------	--------	500	--------	--------	--------
--------	--------	--------	460	--------	--------	--------	--------	75	--------	--------	--------
--------	--------	--------	800	30	4.9	140	73	18	--------	--------	155
--------	--------	--------	410	--------	--------	--------	--------	11	--------	--------	--------
--------	--------	--------	520	--------	--------	--------	--------	13	--------	--------	--------
--------	--------	--------	460	23	2.6	140	trace	28	--------	--------	288
--------	--------	--------	565	17	2.05	170	trace	41	--------	--------	280
--------	--------	--------	1,100	8.4	4.4	66	53	410	--------	--------	81
--------	--------	--------	700	11	15.0	110	14	140	--------	--------	25
--------	--------	--------	2,150	56	0.4	100	87	965	--------	--------	130
--------	--------	--------	1,600	23	trace	130	66	670	--------	--------	114
--------	--------	--------	240	98	7.7	23	6.0	3.3	--------	--------	27
--------	--------	--------	420	14	1.3	94	4.7	42	--------	--------	7.2
--------	--------	--------	1,400	24	0.4	42	3.0	740	--------	--------	1.9
--------	--------	--------	1,000	85	2.0	24	1.0	510	--------	--------	6.7
--------	--------	--------	1,100	27	1.0	26	1.2	600	--------	--------	9.5
--------	--------	--------	1,050	23	0.2	30	little	560	--------	--------	little
--------	--------	--------	1,100	21.5	--------	32	1.3	610	--------	--------	6.1
--------	--------	--------	900	18	2.0	29	1.1	470	--------	--------	12
--------	--------	--------	580	18	3.3	12	trace	280	--------	--------	14
--------	--------	--------	970	18	7.7	21	0.84	540	--------	--------	4.8
--------	--------	--------	1,100	18	1.7	33	0.36	585	--------	--------	130
--------	--------	--------	400	21	0.6	4.7	0.4	100	--------	--------	1.2
--------	--------	--------	700	30	0.8	9.9	4.8	230	--------	--------	1.5
--------	--------	--------	600	--------	--------	--------	--------	165	--------	--------	--------
--------	--------	--------	260	--------	--------	--------	--------	26	--------	--------	--------
--------	--------	--------	340	93	1.2	5.9	1.2	49	--------	--------	--------
--------	--------	--------	1,400	87	trace	39	14	650	--------	--------	2.2

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio,)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
69012		1909	Bulacan, Hagonoy, Inchausti No. 1			
74181		1909	Bulacan, Hagonoy, Inchausti No. 3			
121872		1916	Bulacan, Hagonoy, Santo Niño	121.9	F 38	nil
118110		1914	Bulacan, Marilao			
42794		1907	Bulacan, Malolos, municipal well	56		
47957		1907	Bulacan, Malolos, provincial well			
53508		1907	Bulacan, Meycauayan			
109843	426	1912	Bulacan, Norzagaray	220	P 68	(c)
58273		1908	Bulacan, Obando			
124858	1028	1917	do	130	F 19	nil
125022	1040	1917	do	137	F 38	nil
57479		1908	Bulacan, Polo			
		1911	do			
113638	489	1913	Bulacan, Pulilan	233	F 151	
111547	472	1913	Bulacan, Quingua	216	F 189	
115332	513	1913	Bulacan, San Ildefonso	146	F 76	
117442	531	1913	Bulacan, San Rafael	174	F 95	
102056	389	1912	Bulacan, Santa Maria	169	F 379	(a)
60640		1908	Bulacan, San Miguel de Mayumo, San Miguel			(c)
60639		1908	Bulacan, San Miguel, San Jose			(c)
119411	374-A	1914	Cagayan, Tuguegarao	395	P 114	
79649	146	1910	Capiz, Capiz	306	P 76	
119934	726	1915	Cavite, Bacoor, Alima	56.4	F 49	
120042	746	1915	do	80.4	F 57	
120162	764	1915	do			
123598	772	1916	Cavite, Bacoor, Maliksi	129.8		nil
120815	813	1915	do	136.9	F 76	
123596	830	1916	do	91.4		nil
123599	880	1916	Cavite, Bacoor, Zapote	90.8	F 26	nil
98259		1912	Cavite, Cañacao			
78903	165	1910	Cavite, Caridad	136	P 207	
123030		1916	do			nil
80288	180	1910	Cavite, Imus	72	P 151	
83352	215	1914	do	76	F 26	
119058	659	1914	Cavite, Imus, Talipapa	135.3	F 379	
119172	678	1914	do	77.2	F 57, P 568	
119505	684	1914	do	250.8	P 76	
119623	708	1914	do	91.1	F 227	
119742	718	1915	Cavite, Imus, Medicion 1°	89.3	F 45	
121719	869	1916	do	85.9	F 26	nil
74811	131	1909	Cavite, Cavite	160	P 189	(c)
83799	201	1910	Cavite, Cavite ?	183	F 38, P 227	
118396	611	1914	Cavite, Kawit, Santa Isabel	119	F 61, P 303	
118686	631	1914	do	94.8	F 23, P 379	
118813	646	1914	Cavite, Kawit, Binacayan	125	F 34, P 227	
124592	1008	1917	Cavite, Maragondon	58.8	P 144	nil
124756	1025	1917	Cavite, Kawit	20	P 150	nil
124930	1039	1917	do	80	F 114	nil

[a] Yellow. [c] Brown.

the Philippine Islands—Continued.

Turbidity (SiO2)	Alkalinity (CaCO3).	Acidity (CO2).	Total solids.	Silica (SiO2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO3).	Bicarbonates (HCO3).	Sulphates (SO4).
--------	--------	--------	--------	44	1.25	14	10	100	--------	425	50
--------	--------	--------	--------	36	0.25	43	21.5	290	--------	140	260
nil	189	nil	340	60	0.2	11	1.6	33	nil	230	little
--------	--------	--------	--------	30	0.75	3.7	trace	17	8.6	162	15
--------	--------	--------	880	34	0.5	45	25	420	--------	--------	9.6
--------	--------	--------	610	40.5	0.6	23	14	160	--------	--------	3.0
--------	--------	--------	250	27	1.6	1.6	trace	15	--------	--------	nil
--------	--------	--------	820	18	1.2	26	0.78	440	--------	--------	trace
--------	--------	--------	230	28	1.6	2.0	0.9	24	--------	--------	trace
nil	190	nil	260	23.0	0.13	2.2	trace	15.0	16.8	200.0	trace
nil	180	nil	270	20.0	0.36	trace	trace	18.0	16.8	180.0	trace
--------	--------	--------	220	--------	--------	--------	--------	12	--------	--------	--------
--------	--------	--------	17,000	28	--------	157	210	8,100	--------	--------	836
--------	--------	--------	850	94	3.2	23	3.0	16	--------	--------	12
--------	--------	--------	870	51	trace	29	2.0	420	--------	--------	17
--------	--------	--------	770	36	10.4	11	trace	387	--------	--------	little
--------	--------	--------	2,200	33	3.2	33	0.54	760	--------	--------	trace
--------	--------	--------	280	18	0.6	3.0	0.60	18	--------	--------	21
--------	--------	--------	400	--------	--------	--------	--------	119	--------	--------	--------
--------	--------	--------	380	--------	--------	--------	--------	89	--------	--------	--------
(b)	195	--------	510	28	trace	71.5	11	40	nil	238	5.2
--------	--------	--------	2,870	17	0.6	30	0.87	1,500	--------	--------	250
nil	200	--------	420	65	trace	21	1.0	80	nil	240	8.0
--------	220	2.4	435	90	0.7	12	6.0	46	nil	270	17
n.l	220	--------	365	80	nil	14	nil	20	trace	240	trace
nil	240	--------	410	86	0.10	4.1	1.0	16	6.7	290	<5.0
nil	225	--------	400	85	trace	10	trace	22	nil	270	14
nil	220	--------	520	94	0.35	11	5.4	80	nil	270	<5.0
nil	290	10.0	390	77	0.5	36	18	14	nil	350	<5.0
--------	--------	--------	510	77	1.0	14	5.6	74.5	--------	--------	39
--------	--------	--------	510	71	0.4	9.6	2.1	32	--------	--------	--------
<10.0	340	nil	760	54	1.1	18.0	120	160	nil	410	39
--------	--------	--------	380	84	2.2	37	14	9.6	--------	--------	39
--------	--------	--------	400	89	1.9	40	trace	12	--------	--------	70
--------	--------	--------	380	94	1.7	8.3	3.2	18	--------	--------	11
--------	--------	--------	400	78	12	38	12.5	9.2	--------	--------	12
--------	205	--------	350	67	trace	25	2.2	29	nil	250	16.5
nil	275	--------	390	80	trace	36	15	11	nil	335	1.3
nil	275	--------	440	72.5	trace	43	13	8.0	nil	335	8.0
--------	300	--------	372	78	0.8	50	10.5	7.2	nll	365	little
--------	--------	--------	500	88	1.6	4.6	--------	79	--------	--------	--------
--------	--------	--------	500	81	trace	1.1	0.96	80	--------	--------	23
--------	--------	--------	440	76	1.7	23	9.1	17	--------	--------	43
--------	--------	--------	460	84	3.7	20	11	19	--------	--------	5.6
--------	--------	--------	430	76	1.7	5.5	0.72	23	--------	--------	31
nil	240	19	370	130	0.28	36	16	8.7	nil	300	10
<5.0	290	9.8	470	90	0.16	12	3.8	34	nil	350	3
nil	290	6.5	450	70	0.20	29	10	19	nil	350	trace

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
124774	1023	1917	Cavite, Maragondon	21	P 106	nil
124866	1036	1917	----do	58	P 106	nil
124931	1044	1917	----do	38	P 106	nil
77565	147	1910	Cavite, Naic	49.7	P 57	------
58756	--------	1908	Cavite, Noveleta, Manila R. R. Co.	--------	--------	------
118166	599	1914	----do	93	F 45	------
118262	604	1914	Cavite, Noveleta, San Juan	97.2	P 379, F 95	------
118555	617	1914	Cavite, Noveleta, San Jose	34.4	F 11, P 227	------
77981	135	1910	Cavite, Rosario	116	F 19	------
117646	562	1913	----do	94.5	F 23, P 379	------
117808	574	1913	----do	97.5	F 38	------
117889	585	1913	----do	93.3	F 76, P 379	------
118002	590	1913	Cavite, Rosario, Bagbag	83.5	F 45	------
112413	479	1913	Cavite, San Francisco de Malabon	178	P 57	------
114008	503	1913	----do	158	F 23	------
114934	517	1913	----do	52	F 76	------
115333	527	1913	----do	11	F 57	------
116860	532	1913	----do	166	P 170	(c)
117443	552	1913	Cavite, San Francisco de Malabon, sitios of Bucal and Tejero.	113	P 303	(c)
80790	182	1910	Cavite, San Roque	184	F 114, P 151	------
88873	274	1911	Cavite, Santa Cruz de Malabon	55	P 68	------
88878	289	1911	----do	77	P 76	------
119961	313	1915	Cavite, Santa Cruz de Malabon, Amaya	92	P 113	------
107605	433	1912	Cavite, Santa Cruz de Malabon	247	F 4, P 189	------
109674	457	1912	----do	99	F 38	------
110193	474	1912	----do	76	F 114	------
121241	844	1915	Cavite, Santa Cruz de Malabon, Hulugan	82	F 57	------
121464	855	1915	Cavite, Tanza	93	P 114	------
122018	892	1916	----do	95.4	P 114	nil
122241	901	1916	----do	128	F 114	nil
122402	921	1916	Cavite, Tanza, Jalayjay	107.6	P 76	nil
99397	376	1912	Cebu, Argao	90	P 227	------
121013	831	1915	Cebu, Asturias	62.2	P 76	------
124712	1013	1917	Cebu, Bogo	17	P 19	nil
75585	--------	1910	Cebu, Cavit Island, quarantine station	--------	--------	------
71504	--------	1909	Cebu, Cebu, municipal well	--------	--------	------
117474	--------	1913	Cebu, Cebu, Calle Juan Luna	23	P	------
117475	--------	1913	Cebu, Cebu, Lapulapu	24	P	------
117476	--------	1913	Cebu, Cebu, near railroad station	40	P	------
118277	--------	1914	Cebu, Cebu, Bagumbayan	20	--------	------
117478	--------	1913	Cebu, Cebu, Carbon public market	29	P	------
121877	--------	1916	Cebu, Cebu, customhouse	--------	--------	nil
123124	967	1916	Cebu, Cebu, Piza	26.8	P 265	nil
123177	970	1916	Cebu, Cebu	26.5	P 114	<5
123178	956	1916	----do	26.2	P 265	nil
124518	1018	1917	Cebu, Cebu, Mambalin	33.8	F 114	nil
114822	473	1913	Cebu, Dalaguete	--------	P 227	------

[c] Brown.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
nil	250	30	380	110	0.27	40	14	11	nil	310	trace
2	140	30	350	120	0.48	36	14	8.9	nil	170	nil
nil	210	33	350	110	0.32	39	13	17	nil	260	trace
--------	--------	--------	355	99	6.4	30	9.1	9.4	--------	--------	trace
--------	--------	--------	800	72	0.8	67	12	--------	--------	--------	5.3
--------	--------	--------	430	80	3.7	31.5	--------	10	--------	--------	trace
--------	--------	--------	440	90	0.5	25.5	8.1	12	--------	--------	22
--------	--------	--------	--------	84	0.1	21	2.95	13	--------	--------	11
--------	--------	--------	430	110	3.8	38	9.1	14	--------	--------	trace
--------	--------	--------	440	86	1.2	35	11	12	--------	--------	48
--------	--------	--------	420	79	trace	34	7.2	11	--------	--------	62
--------	--------	--------	420	82	0.5	31	8	13	--------	--------	24
--------	--------	--------	410	--------	--------	--------	--------	9.3	--------	--------	--------
--------	--------	--------	380	84	1.2	21	4.6	16	--------	--------	20
--------	--------	--------	410	84	4.8	9.4	0.42	19	--------	--------	17
--------	--------	--------	360	97	4.8	37	16	6.9	--------	--------	9.4
--------	--------	--------	390	87	3.6	31	7.8	9.9	--------	--------	14
--------	--------	--------	400	88	2	16	trace	14	--------	--------	20
--------	--------	--------	410	88	8	22	4.7	10	--------	--------	11
--------	--------	--------	515	86	1.6	3.8	0.25	76	--------	--------	52
--------	--------	--------	400	81	2.8	40	13	9.9	--------	--------	29
--------	--------	--------	390	79	1.4	36	13	9.9	--------	--------	27
--------	230	--------	340	95	trace	36	16	10	nil	280	4
--------	--------	--------	420	88	4.8	13	4.3	22	--------	--------	29
--------	--------	--------	410	81	2.4	32	11	14	--------	--------	30
--------	--------	--------	370	88	2	32	12	6.9	--------	--------	12
--------	260	--------	430	82.5	0.55	50	16	15	nil	320	--------
--------	230	--------	430	81	0.55	58	9.6	14	nil	280	trace
nil	260	nil	410	80	0.4	32	12	12	trace	320	12
nil	235	16	380	110	0.36	39	13	11	nil	290	13.5
45	240	5.4	390	93	0.5	38	8.9	11	--------	300	11
(b)	--------	--------	520	28	3	33	20	120	--------	--------	63
--------	300	--------	620	15	2.4	25	9.6	130	nil	370	6
<5	190	20	380	trace	0.20	94	21	15	nil	350	trace
--------	5,650	--------	--------	--------	--------	--------	--------	2,800	--------	--------	--------
--------	--------	--------	450	44	0.8	53	14	21	--------	--------	trace
--------	--------	--------	400	--------	--------	--------	--------	9.6	--------	--------	--------
--------	--------	--------	760	--------	--------	--------	--------	91	--------	--------	--------
--------	--------	--------	390	--------	--------	--------	--------	6.9	--------	--------	--------
--------	--------	--------	470	48	2.5	62	20	38	--------	--------	20
--------	--------	--------	540	--------	--------	--------	--------	18.1	--------	--------	--------
nil	430	nil	895	49	0.36	23	20	200	nil	530	47
10	290	20	440	33	0.30	110	14	8.2	nil	350	50
60	270	23	420	33	1.8	100	15	8	nil	350	40
nil	280	28	460	35	0.48	110	16	8	nil	340	60
30	320	14	480	53	3.1	80	23	8.7	nil	390	33
--------	--------	--------	1,400	9.6	3.6	135	39	530	--------	--------	100

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
124427	1012	1917	Cebu, Danao	60.4	P 227	nil
91642	299	1911	Cebu, Mabolo	187	P 379	-------
97268	327	1912	----do	255	P 132	-------
119323	689	1914	Cebu, Toledo	42.7	P 61	-------
120047	682	1915	----do	51.5	P 61	-------
123511	933	1916	Cotabato, Carpenter	44.5	P 151	-------
110499	439	1912	Ilocos Sur, Candon	76	P 38	-------
113543	482	1913	----do	137	P 53	-------
107186	428	1912	Iloilo, Iloilo	77	F 76	(c)
108062	452	1912	----do	77	F 38	(a)
109063	461	1912	----do	79	F 8, P 114	-------
110053	471	1912	----do	79	F 68	(c)
111546	480	1913	Iloilo, Iloilo, Molo	91	F 57	(c)
115624	530	1913	Iloilo, Iloilo	104	F 11	(c)
115942	500	1913	---- do	99	F 76	-------
115946	580	1913	Iloilo, Iloilo, Molo	-------	-------	-------
115947	-------	1913	Iloilo, Iloilo, Ortiz Street	-------	-------	-------
118167	600	1914	Iloilo, Iloilo	80	F 45	-------
117271	541	1913	----do	91	P 57	-------
117452	-------	1913	Iloilo, Iloilo, customhouse	61	F 57	-------
117739	568	1913	Iloilo, Iloilo	78.9	F 11	-------
118057	592	1914	----do	80.5	F 45	(c)
122955	-------	1916	Iloilo, Iloilo, Lapus-lapus	66	P 76	nil
94862	308	1911	Iloilo, Janiuay	348	F 57	(c)
117452	97	1913	Iloilo, Jaro	178	P 76	(c)
115943	-------	1913	Iloilo, Manduriao	-------	-------	-------
85947	218	1911	Iloilo, Pototan	10.7	-------	-------
119138	122	1914	Iloilo, Santa Barbara	152	F 132	(c)
123041	-------	1916	Iloilo, Iloilo, San Miguel road, km. 11	57.9	F 19	5
123136	-------	1916	Iloilo, Iloilo, km. 11.8	48.8	F 45	nil
123311	-------	1916	Iloilo, Iloilo, km. 12.5	-------	F 30	nil
67315	-------	1909	Laguna, Los Baños (?), Bay	70	-------	(a)
120297	756	1915	Laguna, Bay	-------	-------	-------
120627	787	1915	----do	144.8	F 246	-------
93552	330	1911	Laguna, Biñan	93	F 57, P 189	-------
93927	336	1911	----do	75	F 114	-------
94992	343	1911	Laguna, Cabuyao	42	F 454	-------
94993	347	1911	Laguna	40	F 454	-------
121478	805	1915	Laguna, Calauan	181	P 170	-------
97537	356	1912	Laguna, Calamba	110	P 379	-------
118119	587	1914	Laguna, Famy	114	F 68	-------
119055	671	1914	Laguna, Mabitac	93.6	F 114; P 265	-------
122092	871	1916	Laguna, Los Baños	114.3	P 57	nil
115625	526	1913	Laguna, Lumbang	91	F 132	-------
116335	540	1913	----do	128	F 227	-------
116824	548	1913	----do	95	F 151	-------
105449	-------	1912	Laguna, Pagsanjan, No. 39 Calle Blanco	-------	-------	-------
119382	685	1914	Laguna, Pagsanjan	90.2	F 606	-------

[c] Brown. [a] Yellow.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Suphates (SO_4).
8	410	nil	580	30	0.60	19	11	35	20.7	460	25
--------	--------	--------	340	28	4	38	41	6	--------	--------	29
--------	--------	--------	320	43	1.8	105	1.1	7.8	--------	--------	12
--------	--------	--------	800	44	1.7	100	17	160	--------	--------	47
--------	480	--------	1,400	30	0.7	86	30	465	nil	580	77
150	90	19	--------	--------	--------	--------	--------	1,600	nil	110	--------
--------	--------	--------	1,400	12	0.8	4.8	1.4	235	--------	--------	15
(b)	--------	--------	2,500	1.6	0.4	13	8.2	1,100	--------	--------	51
--------	--------	--------	2,200	67	1.6	120	30	730	--------	--------	6.6
--------	--------	--------	2,200	65	trace	120	56	800	--------	--------	5.3
--------	--------	--------	2,750	44.5	9	230	96.5	1,050	--------	--------	15
--------	--------	--------	2,150	72	4	100	48	700	--------	--------	18
--------	--------	--------	1,500	64	1.6	83	48.5	360	--------	--------	49
(b)	--------	--------	3,300	55	8	70	77	1,500	--------	--------	trace
--------	--------	--------	2,200	--------	--------	--------	--------	800	--------	--------	--------
--------	--------	--------	1,600	--------	--------	--------	--------	390	--------	--------	--------
--------	--------	--------	2,700	--------	--------	--------	--------	830	--------	--------	--------
--------	--------	--------	2,300	54	1.7	130	--------	855	--------	--------	trace
--------	--------	--------	1,100	27	trace	6.4	4.4	240	--------	--------	nil
--------	--------	--------	2,200	56	3.2	140	88	870	--------	--------	trace
--------	--------	--------	3,850	52	27	280	170	1,800	--------	--------	trace
--------	--------	--------	2,300	61	10	120	58	875	--------	--------	trace
10	740	38	2,100	41	0.31	160	70	730	nil	900	23
--------	--------	--------	8,200	25.5	10	45	37	4,500	--------	--------	2.05
--------	--------	--------	3,000	58	trace	18	18.5	1,200	--------	--------	trace
--------	--------	--------	1,450	--------	--------	--------	--------	275	--------	--------	--------
--------	--------	--------	630	77	27	110	0.64	76	--------	--------	66
--------	--------	--------	1,100	26	7.7	4.1	0.36	245	--------	--------	2.2
5	475	nil	580	54	0.18	5	5	5.2	6.2	565	trace
nil	340	nil	420	47	0.26	22	23	6.6	nil	420	trace
nil	330	18	410	50	0.38	40	26	6.1	nil	500	trace
--------	--------	--------	790	--------	--------	--------	--------	24	--------	--------	--------
nil	640	--------	720	85	trace	93.5	34	29.5	nil	760	nil
nil	460	--------	470	80	trace	36	22	38	nil	565	nil
--------	--------	--------	390	97	0.1	36	15	15	--------	--------	11.5
--------	--------	--------	380	93	trace	33	17	12	--------	--------	5
--------	--------	--------	755	87	2.2	37.5	18	13	--------	--------	5.6
--------	--------	--------	350	92	0.8	0.28	19	16.5	--------	--------	7.5
--------	460	--------	670	110	2.3	38	29	21	nil	560	nil
--------	--------	--------	370	83	2.2	39	19	8.3	--------	--------	15
--------	--------	--------	255	76	1.7	31	--------	5.4	--------	--------	--------
--------	--------	--------	520	82	0.5	13	2.1	60	--------	--------	1.6
80.0	330	16	470	110	5.2	17	32	37	nil	360	4.9
--------	--------	--------	260	78	3.6	21	5.7	13	--------	--------	nil
--------	--------	--------	320	84	0.8	26	4.3	10	--------	--------	nil
--------	--------	--------	290	79	0.8	21	5.3	13	--------	--------	nil
--------	--------	--------	820	--------	--------	--------	--------	190	--------	--------	--------
--------	--------	--------	740	72	trace	10	16	170	--------	--------	66.4

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
119655	703	1915	Laguna, Pagsanjan	70.7	F 76	
119976	723	1915	Laguna, Pagsanjan, Buboy	183.2	P 265	
114448	508	1913	Laguna, Pila	155	F 322	
58483		1908	Laguna, Santa Cruz, No. 1			
58575		1908	Laguna, Santa Cruz, No. 2			
111668	27	1913	Laguna, Santa Cruz	175	F 757	(c)
107603	440	1912	do	194	F 102	(a)
110480	459	1912	do	175	F 1,325	
112984	493	1913	do	170	F 927	(c)
122359	907	1916	do	193.2	F 53	3.0
122949	949	1916	Laguna, Santa Cruz, Gated	110	F 379	nil
119196	674	1914	Laguna, Santa Maria	187.5	F 64	
92745	326	1911	Laguna, San Pedro Tunasan	108	F 38	
94767	341	1911	Laguna, Santa Rosa	64	F 189	
117609	553	1913	Laguna, Siniloan	121.9	F 151	
117772	566	1913	do	121.9	F 151	
123562	984	1916	Leyte, Baybay	144.8	F 19; P 45	<5.0
124576	998	1917	do	107.9	F 23; P 76	[d] nil
68197	78	1909	Leyte, Carigara	52		(e)
68605		1909	Leyte, Carigara, Sawang			
68956	87	1909	Leyte, Carigara	69		
68930	93	1909	do	52		
15434		1905	Manila, Singalong farm			
32180		1906	Manila, Isla del Provisor	122		
54050		1907	Manila, Manila railroad station			
58254		1908	Manila, Corregidor Island	107	F 265	
58797		1908	Manila, Manila railroad station			
101821		1912	Manila, Santa Cruz, No. 12 (int.) Misericordia			
104361		1912	Manila, Sanitary Steam Laundry			
115482		1913	Manila, San Miguel, Calle Aviles			
117875		1913	Manila, No. 133 Calle Principe			
118013		1914	do (?)			
118752		1914	Manila, St. Scholastica's College			
108775		1912	Manila, San Miguel Brewery			
118904		1914	Manila, Philippine General Hospital grounds			
119326		1914	Manila, No. 1338 Juan Luna			
119426	(?)518	1914	Manila, Insular Ice Plant	229		
121039		1915	do			15.0
121450		1915	Manila, 1001-1023 R. Hidalgo			nil
122494		1916	Manila, Germinal Cigar Factory			nil
123753		1916	Manila, Bureau of Science grounds			nil
118767		1914	Misamis, Agusan, Cabadbaran			
119182		1914	do			
119407	410	1914	Misamis, Cagayan	131	P 568	
118644	484	1914	do	167.6	P 227	
112111		1913	Mountain, Camp John Hay	50.6		
115133	501	1913	Mountain, Tagudin	93	P 57	
117402	515	1913	do	192	F 19	

[a] Yellow. [c] Brown.

the Philippine Islands—Continued.

Turbidity (SiO$_2$).	Alkalinity (CaCO$_3$).	Acidity (CO$_2$).	Total solids.	Silica (SiO$_2$).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO$_3$).	Bicarbonates (HCO$_3$).	Sulphates (SO$_4$).
nil	150	-------	400	80	0.1	21.5	8.7	41	nil	190	25
(b)	525	-------	860	80	0.4	82	83	160	nil	640	14
-------	-------	-------	215	73	trace	17	12	5.4	-------	-------	trace
-------	-------	-------	220	76	2.4	15	9.4	5.5	-------	-------	nil
-------	-------	-------	450	72	4.0	21	16	20	-------	-------	trace
-------	-------	-------	430	90	2.0	37	8.9	20	-------	-------	7.7
-------	-------	-------	490	110	4.4	28	5.1	24	-------	-------	9.0
-------	-------	-------	450	98	1.6	29	5.1	20	-------	-------	trace
-------	-------	-------	450	94	2.0	35	6.3	20	-------	-------	trace
50	430	16	617	62	1.4	19	7.5	62.5	-------	520	trace
<5.0	180	nil	260	70	0.28	20	12	9.1	nil	220	trace
-------	-------	-------	1,300	38	16	61	26.5	280	-------	-------	360
-------	-------	-------	400	93	trace	50	10.0	6.9	-------	-------	16
-------	-------	-------	390	100	trace	44	15	16	-------	-------	17
-------	-------	-------	230	40	3.2	17	5.3	17.5	-------	-------	nil
-------	-------	-------	240	54	4.4	24	4.3	13	-------	-------	trace
5.0	220	4.6	820	55	1.0	37	14	310	nil	270	nil
20	220	nil	810	85	0.66	34	25	300	nil	270	trace
-------	-------	-------	1,300	110	2.0	270	62	35	-------	-------	10
-------	-------	-------	1,300	110	4.0	340	90	36	-------	-------	16
(b)	-------	-------	1,200	-------	-------	-------	-------	39	-------	-------	-------
(b)	-------	-------	1,500	-------	-------	-------	-------	43	-------	-------	-------
-------	-------	-------	900	trace	trace	13	trace	190	-------	-------	165
-------	-------	-------	1,800	55	0.40	46.5	0.72	-------	-------	-------	108
-------	-------	-------	1,800	35	1.6	57	23	870	-------	-------	28
-------	-------	-------	660	71	2.8	51	24	86	-------	-------	trace
-------	-------	-------	220	22	0.4	1.7	trace	-------	-------	-------	trace
(b)	-------	-------	270	-------	-------	-------	-------	31	-------	-------	-------
-------	-------	-------	250	-------	-------	-------	-------	35	-------	-------	-------
-------	-------	-------	310	-------	-------	-------	-------	50	-------	-------	-------
-------	-------	-------	2,100	-------	-------	-------	-------	100	-------	-------	-------
-------	-------	-------	545	65	7.0	11	trace	-------	-------	-------	trace
-------	-------	-------	690	-------	-------	-------	-------	150	-------	-------	-------
-------	-------	-------	594	25	8.6	19	11	210	-------	67	114
-------	-------	-------	540	62	trace	5.5	trace	30	-------	-------	3.3
-------	-------	-------	630	66	1.7	6.9	2.1	160	-------	-------	20
nil	68	-------	250	26	trace	1.8	nil	32.5	nil	83	66.5
-------	70	-------	260	31	trace	3.0	trace	34.5	18	49	38
-------	48	-------	380	43	0.3	6.4	trace	35	15.5	26	130
nil	75	-------	375	13	trace	4.6	trace	57	8.9	73	120
10.0	290	nil	730	50	1.5	6.9	0.4	69	14	320	150
-------	-------	-------	230	22	1.7	17	6.4	2.4	-------	-------	11
-------	-------	-------	170	74	16	14	11	1.9	-------	-------	0.6
(b)	460	-------	1,300	10	10	20	33	440	nil	560	6.0
-------	-------	-------	490	70	22	2.6	17	30	-------	-------	nil
-------	-------	-------	120	40	5.2	19	2.1	2.5	-------	-------	trace
-------	-------	-------	790	22	trace	2.9	0.78	390	-------	-------	nil
-------	-------	-------	790	20	trace	7.1	trace	400	-------	-------	trace

[b] Turbid.

[c] Green.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
118958	613	1914	Nueva Ecija, Aliaga	142.3	F 42	------
120313	769	1915	-----do	129.8	F 151	------
120867	788	1915	-----do	157.9	F 170	------
122810	908	1916	-----do	175.6	F 45	nil
94613	317	1911	Nueva Ecija, Cabanatuan	189	F 284	------
119531	691	1914	-----do	185.3	F 45	------
119755	716	1915	-----do	138.7	F 132	------
120056	731	1915	Nueva Ecija, Cabanatuan, Mayapyap	136.9	F 151	------
123431	959	1916	Nueva Ecija, Cabanatuan	222.5	F 28	nil
124253	992	1917	-----do	138.7	F 26	nil
119074	662	1914	Nueva Ecija, Cuyapo	132.6	F 95	------
119257	677	1914	-----do	110.9	F 151	------
119595	687	1914	-----do	170.1	F 8; P 151	------
79220	179	1910	Nueva Ecija, Gapan	25	P 76	(c)
82585	214	1910	-----do	24	P 132	------
120303	762	1915	-----do	------	------	------
121120	821	1915	-----do	146.3	F 114	nil
121502	848	1915	Nueva Ecija, Gapan, Baluarte	107.3	F 19	nil
121834	864	1916	Nueva Ecija, Gapan, Santo Cristo	99.1	F 45	nil
119699	711	1915	Nueva Ecija, Nampicuan	92	F 473	------
119843	724	1915	-----do	102.7	F 530	------
119897	737	1915	-----do	32	F 76	------
120018	749	1915	Nueva Ecija, Nampicuan, Alemania	107	F 379	------
122083	884	1916	Nueva Ecija, Quezon	114.9	F 95	nil
122646	887	1916	Nueva Ecija, San Antonio	182.3	F 114	nil
123512	947	1916	-----do	213.4	F 11	nil
120603	789	1915	Nueva Ecija, San Isidro, Pulo	128.6	F 30	------
124519	1009	1917	Nueva Ecija, Zaragoza	101.2	F 34	nil
118529	597	1914	Occidental Negros, Bacolod	164.0	P 151	------
118597	629	1914	-----do	33.5	P 76	------
118654	633	1914	-----do	43.9	P 265	------
118687	634	1914	-----do	36.9	P 76	------
118905	635	1914	-----do	30.5	P 114	------
118906	650	1914	-----do	28.3	P 76	------
119186	653	1914	-----do	27.4	P 76	------
119187	661	1914	Occidental Negros, Bacolod, Tangut	58.2	P 57	(c)
119188	664	1914	Occidental Negros, Bacolod, Sumog	84.4	P 95	------
122972	945	1916	Occidental Negros, Binalbagan	136.9	F 11; P 284	[d] nil
122872	937	1916	Occidental Negros, Cadiz	79.2	P 132	nil
122871	954	1916	-----do	75	F 19	nil
121000	752	1915	Occidental Negros, Escalante	16.2	P 76	------
122126	825	1916	-----do	4.3	P 212	nil
122858	883	1916	Occidental Negros, Hinigaran, Narauis	32.6	P 76	nil
122859	889	1916	Occidental Negros, Hinigaran, Paticui	59.4	P 76	nil
122366	897	1916	Occidental Negros, Hinigaran	20.1	P 76	nil
123492	909	1916	-----do	42.7	P 114	nil
122973	915	1916	Occidental Negros, Isabela	33.2	P 189	[d] 5.0
122367	919	1916	-----do	29.6	P 76	nil

[c] Brown. [d] Filtered.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
-------	-------	-------	200	22	0.3	3.8	1.0	7.0	-------	-------	nil
nil	160	-------	210	19	trace	7.2	trace	9.0	12	170	nil
nil	150	-------	210	12	trace	7.0	trace	20	trace	190	6.0
nil	135	nil	180	9.0	0.33	4.5	trace	9.4	11	140	trace
-------	-------	-------	240	23	trace	3.1	0.48	29	-------	-------	19
-------	130	-------	200	15	nil	5.0	nil	15.5	nil	70	2.1
nil	115	-------	210	15	nil	1.7	nil	24	nil	140	2.0
-------	110	-------	205	16	-------	4.5	2.0	30	13	95	9.2
<5.0	190	nil	240	17	0.36	2.1	0.7	11	21	190	trace
nil	160	nil	230	15	0.10	2.9	trace	18	21	160	trace
-------	-------	-------	270	3.7	1.7	18	2.95	3.2	-------	-------	nil
-------	-------	-------	370	36	3.7	30	8.2	1.0	-------	-------	8.9
nil	220	-------	380	45	trace	23.2	5.5	8.2	nil	270	1.0
-------	-------	-------	570	55	3.2	100	21	76	-------	-------	35
-------	-------	-------	320	60	1.8	58	16	11	-------	-------	4.4
nil	200	-------	275	20	trace	3.5	trace	15	24	240	trace
-------	200	-------	280	20	0.2	7.1	trace	12	8.9	230	120
-------	180	-------	370	13	0.4	7.1	trace	58	trace	220	trace
nil	220	-------	300	19	0.2	little	trace	27	12	270	trace
(b)	260	-------	380	27.5	trace	14	5.0	10	nil	320	6.0
nil	255	-------	365	30	nil	7.0	2.2	10	nil	310	trace
nil	250	-------	435	45.5	nil	39	23	34	nil	305	14
nil	225	-------	350	16.5	trace	trace	7.5	32	nil	270	12
nil	180	nil	245	27	0.44	2.1	trace	11	5.9	210	4.5
nil	240	nil	355	15	0.35	10	trace	22	11	290	8.0
nil	270	nil	360	23	0.52	4.0	trace	9.7	21	290	trace
nil	175	-------	265	22.5	trace	7.2	trace	18	36	210	21
nil	180	nil	420	23	0.36	6.8	trace	21	17	190	6.1
-------	-------	-------	320	100	7.7	20	9.5	9.0	-------	-------	4.2
-------	-------	-------	240	100	1.7	15.5	7.3	65	-------	-------	330
-------	-------	-------	240	120	9.7	8.3	0.06	6.4	-------	-------	trace
-------	-------	-------	250	-------	-------	-------	-------	3.0	-------	-------	-------
-------	-------	-------	270	100	0.3	20	22.5	6.5	-------	-------	43
-------	-------	-------	290	110	1.7	20	19	4.0	-------	-------	2.0
-------	-------	-------	260	88	7.7	11	5.6	5.4	-------	-------	9.7
(b)	-------	-------	320	100	24	11	5.6	3.8	-------	-------	nil
-------	-------	-------	360	100	1.7	21	24	29	-------	-------	29
150	310	24	-------	-------	-------	-------	-------	1,700	nil	370	-------
<10	210	5.0	310	74	1.1	30	18	10	nil	260	trace
5.0	210	5.0	310	58	1.2	33	16	10	nil	260	13
-------	325	-------	545	20	1.2	140	19	34	nil	400	14
nil	340	16	445	12	0.24	110	11	16	nil	410	trace
10	390	14	790	72	0.64	12	11	125	nil	480	50
nil	270	5.0	550	90	0.98	little	trace	70	nil	330	21
70	320	16	-------	58	2.1	66	29	365	-------	385	trace
60	250	4.6	760	50	0.70	37	40	230	nil	310	trace
300	120	24	215	45	10	27	8.3	7.3	nil	150	<1.0
high	120	10.7	250	92	4.2	26	7.2	12	-------	150	trace

[b] Turbid. [e] Green.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
122974	931	1916	Occidental Negros, Isabela	30.5	P 227	[d]<5.0
122975	936	1916	----do	? 26.2	P 227	[d]<5.0
122976	943	1916	----do	27.4	P 76	[d] nil
120981	771	1915	Occidental Negros, La Carlota	46.9	P 61	------
121853	776	1916	----do	50	P 68	<5.0
120932	778	1915	----do	43.3	P 57	------
120933	790	1915	----do	33.2	P 68	------
120934	801	1915	----do	14.3	P 246	------
121420	807	1915	----do	19.8	F 26	nil
121421	808	1915	----do	35.7	P 95	------
121422	816	1915	----do	33.8	P 76	------
121423	817	1915	----do	16.5	P 303	------
121424	818	1915	----do	46.3	P 61	------
121425	823	1915	----do	33.5	P 45	------
121854	827	1916	----do	13.7	P 322	nil
121426	828	1915	----do	20.4	F 34	nil
121855	833	1916	----do	18.3	P 379	nil
121427	834	1915	Occidental Negros, La Carlota, Tabao	17.7	P 284	nil
118094	538	1914	Occidental Negros, Murcia	209.4	P 95	(c)
122127	858	1916	Occidental Negros, Sagay	158.5	P 76	95.0
111866	462	1913	Occidental Negros, San Carlos	139	F 57	------
119185	594	1914	----do	245.4	P 114	(c)
119977	707	1915	----do	198.1	P 38	(a)
120598	795	1915	Occidental Negros, San Enrique	22.6	P 76	------
120597	796	1915	----do	22.9	F 38	------
119907	733	1915	Occidental Negros, Valladolid, Pulupandan	19.5	P 76	------
119991	734	1915	Occidental Negros, Valladolid, Paloca	21.9	P 95	------
120137	740	1915	Occidental Negros, Valladolid	------	------	------
120136	741	1915	----do	------	------	------
120928	745	1915	----do	28.3	P 95	------
120929	750	1915	----do	22.3	P 76	------
120930	759	1915	----do	40.5	P 95	------
121654	851	1915	Oriental Negros, Ayuquitan	32	P 95	------
121728	867	1916	Oriental Negros, Ayuquitan, Amblang	58.2	P 201	nil
122336	875	1916	Oriental Negros, Ayuquitan	32.6	P 227	nil
122024	893	1916	Oriental Negros, Ayuquitan, Tandayag	40.5	P 114	nil
122118	900	1916	Oriental Negros, Ayuquitan	43.9	P 265	nil
122257	905	1916	----do	42.1	P 132	5.0
122288	918	1916	----do	26.2	P 136	------
119102	621	1914	Oriental Negros, Bacong	150	P 95	------
123354	969	1916	Oriental Negros, Bais	80.5	P 95	nil
123821	987	1916	Oriental Negros, Bais, Cambagroy	56.4	P 57	<5.0
123822	994	1916	Oriental Negros, Bais, plaza	77.7	P 76	nil
119090	654	1914	Oriental Negros, Dauin	65.5	P 76	------
118410	588	1914	Oriental Negros, Dumaguete	141.7	F 151	------
118478	620	1914	----do	6.7	F 1,136	------
121056	829	1915	Oriental Negros, Sibulan	71.6	P 38	nil
121653	842	1915	Oriental Negros, Sibulan, Bolocboloc	48.8	P 38	nil

[a] Yellow. [c] Brown.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
150	120	24	280	100	2.4	28	4.7	8.2	nil	150	1.4
300	130	29	300	100	6.4	35	6.3	28	nil	160	trace
100	170	14	280	70	2.8	43	8.7	8.5	nil	210	nil
(b)	225	-------	375	65	2.4	39	15	6.5	nil	270	21
(b)	219	9.0	330	88	4.3	75	13	7.2	nil	270	23
nil	190	-------	335	80	1.5	29	16	6.0	nil	235	16.5
(b)	210	-------	355	65	2.4	39	17	7.0	nil	260	16.5
nil	190	-------	325	70	0.3	21.5	12	13	nil	285	12
-------	220	-------	350	91	0.25	46	16	7.2	nil	270	14
(b)	200	-------	335	79.5	2.8	35	16	-------	nil	250	13
(b)	190	-------	310	81.5	2.2	19	11	7.2	nil	230	13
(b)	-------	-------	300	96.5	1.1	34	13	5.15	nil	230	trace
(b)	200	-------	310	80	2.8	31	15	7.2	nil	240	trace
(b)	190	-------	305	86	1.7	34	16	6.2	nil	230	trace
(b)	159	13	260	110	1.0	130	16	5.1	nil	194	trace
-------	175	-------	310	100	0.4	34	12	9.3	nil	210	trace
nil	194	4.3	330	94	0.6	19	11	12	nil	240	trace
-------	200	-------	350	82	0.7	13	20	14	nil	240	16.5
(b)	-------	-------	160	46.5	4.5	17	10	11	-------	-------	6.2
20	410	nil	650	12	2.6	16	5.7	62	12	480	42
-------	-------	-------	310	37	3.2	19	3.37	7.9	-------	-------	26
-------	-------	-------	360	14	1.7	1.2	nil	32	-------	-------	16
nil	250	-------	330	30	trace	trace	trace	10	nil	260	trace
nil	185	-------	315	90	trace	23	11	12.5	nil	230	trace
nil	190	-------	320	82.5	trace	29	11	15	nil	230	trace
nil	360	-------	2,600	70	0.8	25	42	1,020	nil	440	220
nil	245	-------	400	90	trace	trace	trace	3.0	-------	340	12
nil	250	-------	1,200	80	trace	12.5	24	372	nil	300	110
(b)	180	-------	360	90	trace	26	11	17	nil	220	45
nil	220	-------	585	70	0.6	14	7.6	84	nil	270	41
nil	200	-------	415	80	1.8	21.5	13	14	nil	240	51
nil	210	-------	390	70	1.5	25	11	16	nil	260	12
-------	270	-------	500	84.5	0.55	102	17	45	nil	330	12
-------	130	-------	460	34	0.7	trace	7.4	140	17.0	140	33
5.0	180	16	2,400	64	0.4	110	51	1,109	-------	225	100
nil	114	nil	340	38	0.32	trace	little	60	nil	140	trace
50	274	nil	500	58	5.4	32	60	58	nil	330	35
100	210	27	330	80	2.04	53	17	11.5	nil	260	10
-------	280	-------	590	42	0.6	trace	trace	83	12	340	49
-------	-------	-------	250	100	12	17	4.3	4.3	-------	-------	23.64
10	190	nil	260	28	0.48	27	7.0	7.5	nil	240	22
<20	250	nil	960	30	2.0	56	30	340	nil	300	42
10	220	nil	430	22	0.48	27	14	87	nil	270	15
(b)	-------	-------	388	100	3.7	40	8.7	40	-------	-------	64
-------	-------	-------	2,320	22	1.7	150	93	1,080	-------	-------	160
-------	-------	-------	220	100	1.7	18	4.0	6.9	-------	-------	16
-------	160	-------	740	60	trace	60	14	60	nil	192	37
-------	69	-------	370	100	0.7	40	12.5	47	nil	85	60

[b] Turbid. [d] Filtered.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
119409	676	1914	Oriental Negros, Zamboanguita	42.7	P 303	
117541		1913	Palawan, Iwahig Penal Colony			
117565	525	1913	do	139.9	P 95	(c)
61055		1908	Pampanga, Arayat, Santa Ana			
111327	470	1913	Pampanga, Arayat	157	P 303	
113697	492	1913	do	183	P 189	
48270		1907	Pampanga, Bacolor			
61945		1908	Pampanga, Bacolor, Tinajero			
62810		1908	Pampanga, Bacolor, Cabetican			(c)
62811		1908	Pampanga, Bacolor, Cabalantian			
113343		1913	Pampanga, Bacolor			
106871	434	1912	Pampanga, Candaba	91	F 189	
108533	450	1912	do	102	P 189	(c)
48268		1907	Pampanga, Guagua			
61343		1908	Pampanga, Guagua, Betis			(c)
48269		1907	Pampanga, Lubao			
59529		1908	Pampanga, Lubao (B. Legarda's)			
59530		1908	do			
119337		1914	Pampanga, Lubao			(a)
116861	519	1913	Pampanga, Mabalacat		P 95	
48263		1907	Pampanga, Macabebe		F 227	
48214		1907	Pampanga, Mexico		F 13	
48312		1907	Pampanga, Minalin			
43673		1907	Pampanga, San Esteban, hacienda (provincial well).			
48210		1907	Pampanga, San Fernando (municipal well)		F 38	
59195		1908	do			
59955		1908	Pampanga, San Fernando, San Jose			
72249		1909	Pampanga, San Fernando, at new market			
70464	("A")	1909	Pampanga, San Luis, at market			
70464	("B")	1909	Pampanga, San Luis, Santa Cruz			(c)
64527		1909	Pampanga, Santa Rita, San Jose			
64528		1909	Pampanga, Santa Rita, San Matias			
67353		1909	Pampanga, Santa Rita, San Isidro			
68471		1909	Pampanga, Santa Rita, Santa Monica			
69116		1909	Pampanga, Santa Rita, San Vicente			
72964		1909	Pampanga, Santa Rita, San Juan			
39318		1907	Pampanga, Santo Tomas			
58527		1908	do			
61056		1908	Pampanga, Sexmoan			
121974	853	1916	Pangasinan, Aguilar	31.4	F 8; P 76	nil
106337	415	1912	Pangasinan, Alcala	182	F 568	
118044	535	1914	Pangasinan, Asingan	93.3	P 379	
121049	832	1915	do	24.4	P 227	nil
121506	837	1915	Pangasinan, Asingan, Macalong	61.3	P 114	nil
121937	870	1916	Pangasinan, Asingan	102.4	P 76	nil
119437	655	1914	Pangasinan, Balungao	229.2	P 38	
85906	226	1911	Pangasinan, Bayambang	117	F 6; P 95	(c)

[c] Brown. [a] Yellow.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
nil			240	90	trace	22.5	5.4	4.2	nil	120	20
			28					trace			nil
			410	50	1.2	25	80	11.5			1.7
(b)			290					7.2			
			390	100	2.4	12	7.5	12			14
			550	110	2.4	6.3	1.6	19			30
			450	90	0.6	3.6	0.9	14			nil
			570					30			
			650					42			
			520					36			
			280					8.3			
			400	90	1.6	3.4	trace	6.0			280
			420	75	1.6	5	0.18	8.8			19
			1,200	80	2.8	11	12.5	305			trace
			1,000					250			
			310	80	0.8	2.6	1.9	3.5			1.9
			390	90	2.0	24	12				faint
			380	83	0.8	23	11				faint
			310	80	1.7	2.6	0.78	9.7			nil
			250	90	6.4	25	10	4.2			20
			359	40	1.0	17	3.4	58			1.5
			430	80	1.4	1.8	1.0	34.5			2.8
			230	30	1.8	13	1.4	9.2			0.66
			1,020					135			
			420	80	0.6	3.4	1.4	55			2.6
			470					30			
			490					20			
			400					10			
			280					13			
			480					32			
			260					11			
			250					6.8			
			250					7.6			
			290					8.2			
			260					8.7			
			320					8.5			
			465					4.4			
			240	40	4.0	13	2.0	8.0		185	20
			495					16			
90	72	nil	510	70	3.8	trace	trace	36	47	88	189
			230	40	0.6	5.0	trace	20			17
			270	70	7.7	41.5	4.2	12			76
	157		260	30	trace	62	12	14	nil	190	18
	110		210	40	0.5	60	trace	11	nil	130	trace
45	120	nil	250	100	1.1	27	5.0	15	nil	150	9.0
(b)	40		515	35	trace	21	1.2	220	nil	50	24.5
			810	50	4.6	50	5.8	360			13

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
86306	259	1911	Pangasinan, Bayambang	30.5	F 1,893	
69857		1909	Pangasinan, Bautista (property of Matias Gonzales).			(c)
80060	181	1910	Pangasinan, Bautista	75	F 38	
123771		1916	Pangasinan, Bautista (property of Y. Sontua)	112.8		nil
115144	521	1913	Pangasinan, Binalonan	82	P 454	
121022	824	1915	do	52.4	P 95	
94707	335	1911	Pangasinan, Binmaley	120	F 132; P 265	
68617	80	1909	Pangasinan, Calasiao	58	F 189	
60753		1908	Pangasinan, Dagupan	125		
67973	75	1909	do	67	F 568	
117520	556	1913	do	68	F 227	
121956		1916	do			nil
64008	89	1909	Pangasinan, Lingayen	198	F 189	
64559		1909	do			
114821	486	1913	do	268	F 757	(a)
116862	533	1913	do	166	F 170	
124905		1917	Pangasinan, Lingayen, capitol site			
91192	310	1911	Pangasinan, Malasiqui	91	P 946	
119637	698	1915	do	133.8	P 227	
119936	727	1915	Pangasinan, Manaoag	119.8		
120889	811	1915	Pangasinan, Manaoag, Pan	19.8	P 170	
93693	328	1911	Pangasinan, Mangaldan	32	F 284	
119676	714	1915	do	53.3	F 322	
119721	722	1915	do	48.8	F 283.9	
123785		1916	do	107		nil
120464	761	1915	Pangasinan, Mangatarem	31.7	P 227	
120615	803	1915	do	32.6	F 227	
120907	810	1915	do	36.6	P 227	
120974	835	1915	do	25.9	P 227	
121064	840	1915	do	21.3	F 151	nil
121240	845	1915	do	29	P 284	nil
123128	962	1916	Pangasinan, Natividad	25.6	F 114	nil
120789	782	1915	Pangasinan, Pozorrubio	27.7	P 189	
118045	558	1914	Pangasinan, Rosales	107.6	P 379	
119079	602	1914	do	220.7	P 227	
122065	898	1916	Pangasinan, Salasa	47.6	F 57	nil
122240	902	1916	do	85.6	F 379	nil
123129	923	1916	Pangasinan, Salasa, Samat	256.6	F 38	<5.0
123122	940	1916	Pangasinan, Santa Barbara	114.6	F 76; P 95	nil
69625	90	1909	Pangasinan, San Carlos	132		
92450	325	1911	Pangasinan, San Fabian	35	F 606	
122537	927	1916	do	29.3	F 170	nil
105444	408	1912	Pangasinan, San Jacinto	137	F 95	
122189	899	1916	Pangasinan, San Manuel	29.3	P 61	5.0
123216-A	975	1916	Pangasinan, San Nicolas	29.6	F 227	nil
123393	985	1916	do	28	P 95	nil
124577	991	1917	Pangasinan, San Quintin	33.2	P 95	

[a] Yellow. [c] Brown.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
------	------	------	310	33	1.4	10	3.9	50	------	------	30
(b)	------	------	290	------	------	------	------	32	------	------	------
------	------	------	260	72	0.8	4.1	slight	22	------	------	23
112	160	nil	730	40	0.56	24	2.4	240	nil	200	60
------	------	------	225	34	little	------	2.5	1.5	------	------	36
------	150	------	250	15	------		------	6.2	nil	18	25
------	------	------	800	48	8.7	18	5.7	140	------	------	15
------	------	------	350	80	0.4	11	1.4	23	------	------	trace
------	------	------	120	40	0.8	6.0	0.72	120	------	------	trace
(b)	------	------	270	26	0.2	11	0.66	3.6	------	------	28
------	------	------	2,300	50	4.8	92	38	1,100	------	------	26
nil	400	5.3	1,500	40	0.28	36	23	605	nil	490	12
------	------	------	600	18	3.2	17	1.9	230	------	------	trace
------	------	------	780	23	2.6	29	2.5	360	------	------	3.6
------	------	------	1,240	45	3.2	70	3.9	600	------	------	0.24
------	------	------	595	50	2.0	24	little	180	------	------	trace
------	------	------	1,900	------	------	------	------	900	------	------	------
------	------	------	790	60	1.8	93	24.7	11	------	------	60
(b)	210	------	690	50	1.0	35	11	250	nil	260	trace
nil	115	------	320	60	nil	13.5	trace	74	nil	140	28
nil	280	------	400	50	3.0	67	16	12	nil	345	10
------	------	------	760	38	1.8	12	6.4	160	------	------	22
nil	220	------	440	35	trace	29	3.4	29	nil	268	21
nil	240	------	440	25	trace	28	9.0	34	nil	290	17
5	180	nil	450	47	0.16	16	1.3	150	nil	220	32
nil	195	------	275	50	trace	36	35	19	nil	240	nil
nil	180	------	230	50	trace	21.5	33.0	13	nil	220	nil
nil	165	------	270	45	trace	45	35	9	nil	200	trace
nil	230	------	320	52	trace	68	33	14	nil	280	6.2
------	173	------	290	47	trace	33	33	27	nil	210	23
------	160	------	220	60	0.15	17	31	10	nil	195	trace
5	90	10	140	35	0.60	20	7.7	3	nil	120	trace
nil	235	------	350	45	3.0	70	15	5.5	nil	290	20
------	------	------	320	34	1.7	55	14	11	------	------	6.4
------	------	------	190	18	1.7	8.3	6.9	7.3	------	------	nil
nil	200	------	260	46	0.62	85	21	11	nil	240	40
nil	210	nil	400	30	0.16	17	5.0	70	nil	255	9.4
50	60	nil	------	------	------	------	------	1,700	nil	70	------
10	150	nil	290	35	0.4	20	3.1	14	nil	180	<5.0
------	------	------	1,440	------	------	------	------	780	------	------	------
------	------	------	250	40	2.4	56	4.8	3.0	------	------	33
5	170	nil	190	23	0.34	64	6.6	5.8	nil	210	46
------	------	------	270	33	4.4	45	4.2	1.5	------	------	38
130	110	5.8	290	93	3.5	45	4.6	16	nil	130	27
<5	130	9.2	170	27	0.26	28	2.1	4.5	nil	150	trace
<5	110	4.6	160	29	0.36	27	10	5.2	nil	130	<5.0
35	120	nil	200	38	0.92	28	10	5.2	nil	140	11

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
108254	445	1912	Pangasinan, Santo Tomas	142	F 61	------
117102	516	1913	----do	179	F 61	------
106814	403	1912	Pangasinan, Sual	98	F 76	------
122783	920	1916	Pangasinan, Tayug	148.1	P 57	nil
122948	958	1916	----do	33.5	P 114	[d] nil
124859	1021	1917	Pangasinan, Umingan	128	P 76	nil
124962	1043	1917	Pangasinan, Umingan, San Leon	36.6	P 95	nil
118174	598	1914	Pangasinan, Urdaneta	77.7	F 95	------
118300	605	1914	----do	84.7	F 57	------
118411	614	1914	Pangasinan, Urdaneta, Mabini	71.3	F 341	------
118617	630	1914	Pangasinan, Villasis	31.7	F 76	------
118746	637	1914	----do	40.8	F 265	------
118812	642	1914	Pangasinan, Villasis, San Blas	29.9	F 190	------
119057	645	1914	Pangasinan, Villasis	72.5	P 227	------
87525	257	1911	Rizal, Alabang	302	P 379	(c)
88594	283	1911	----do	174	P 681	------
94089	------	1911	Rizal, Alabang, stock farm	------	------	------
93776	323	1911	Rizal, Antipolo	78	P 189	------
96857	302	1912	----do	246	P 76	------
97143	------	1912	Rizal, Antipolo, magnetic station	------	------	------
117570	565	1913	Rizal, Antipolo	19.5	P 132	------
117683	570	1913	----do	11.9	P 151	------
117992	557	1913	----do	96	P 132	------
112549	447	1913	Rizal, Binangonan	223	P 379	------
113818	504	1913	----do	94	P 189	------
121664	------	1916	Rizal, Binangonan, cement factory	------	------	5.0
122139	894	1916	Rizal, Binangonan	40.8	P 57	nil
122360	910	1916	----do	84.4	P 76	nil
122538	928	1916	----do	72.8	P 57	nil
122698	941	1916	----do	73.1	P 57	nil
123053	951	1916	----do	30.5	P 38	nil
123195	965	1916	----do	55.5	P 76	nil
123457	983	1916	----do	34.8	P 57	[d] nil
123617	993	1916	----do	42.7	P 151	nil
124449	1014	1917	Rizal, Cainta	45.4	P 38	nil
124586	1019	1917	Rizal, Cainta, Santo Niño	61	P 38	nil
118055	105	1914	Rizal, Caloocan	218	F 76	------
119335	683	1914	----do	204.8	F 15; P 76	------
119548	695	1914	----do	182.8	F 95	------
122113	895	1916	Rizal, Caloocan, Balintauac	123.4	P 76	nil
122190	906	1916	Rizal, Caloocan	86.9	P 76	nil
122389	916	1916	----do	87.5	P 76	nil
122539	925	1916	----do	71.6	P 76	nil
122736	938	1916	----do	65.5	P 189	nil
122890	950	1916	Rizal, Caloocan, Kaypascuala	92.4	P 132	nil
119614	546	1914	Rizal, Cardona	19.8	P 114	------
119692	720	1915	----do	31.1	P 114	------
119334	520	1914	Rizal, Jalajala	163.1	P 57	------

[c] Brown. [d] Filtered.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
----	----	----	275	63	1.0	34	6.6	15	----	----	21
----	----	----	310	80	0.8	26	4.3	4.7	----	----	nil
----	----	----	320	70	1.6	105	23	265	----	----	45
20	170	2.5	230	40	0.75	10	2.0	9.0	nil	200	trace
180	150	9.5	230	80	2.0	33	10	5.5	nil	180	trace
20	130	nil	250	22	1.1	9.8	0.55	22	5.6	150	19
10	240	6	290	35	0.40	45	13	3.4	nil	290	nil
----	----	----	270	80	3.7	31	----	15.0	----	----	----
----	----	----	265	85	3.7	30	2.5	16	----	----	34
----	----	----	270	85	0.5	30	3.4	17	----	----	31
----	----	----	230	42	nil	35	0.06	9.2	----	----	16
----	----	----	250	40	1.7	33	24	9.7	----	----	12
----	----	----	250	----	----	----	----	9.7	----	----	----
----	----	----	240	40	3.7	34	5.2	14	----	----	25
----	----	----	410	90	1.8	34	9.4	17	----	----	16
----	----	----	440	80	3.6	27	5.7	27	----	----	21
----	----	----	440	90	trace	28	6.5	30	----	----	2.4
----	----	----	200	120	trace	16	3.5	8.9	----	----	3.8
----	----	----	465	80	6.4	60	18	80	----	----	17
----	----	----	230	50	trace	70	trace	7.0	----	----	25
(b)	----	----	300	120	4.0	28	5.0	14.0	----	----	4.3
----	----	----	190	----	----	----	----	4.0	----	----	----
----	----	----	230	110	0.9	20	6.3	3.0	----	----	2.5
----	----	----	470	70	1.4	30	28	63	----	----	13
(b)	----	----	460	90	trace	50	2	35	----	----	70
----	80	trace	185	25	3.0	trace	trace	35	nil	100	21
20	310	16	645	40	0.84	70	35	70	nil	380	45
55	300	27	520	100	1.7	30	16	56	----	360	trace
7	270	9.3	480	44	0.42	30	28	70	nil	340	8.3
nil	300	4.6	430	40	0.38	30	27	38	nil	370	8.4
5	365	70	465	90	0.32	60	31	12	nil	445	<5.0
10	290	4.6	410	70	0.50	30	30	25	nil	360	<5.0
20	210	35	360	100	0.70	44	10	10	nil	260	4.4
5	170	9.0	580	100	0.40	45	9.0	37	nil	210	160
<5	210	14	730	100	0.56	140	11	140	nil	260	93
nil	180	4.6	730	90	nil	80	24	160	nil	220	110
----	----	----	320	40	8.6	4.4	trace	10	12.0	250	24
----	----	----	300	45	nil	trace	trace	17	----	----	2.3
nil	185	----	325	20	nil	3.6	1.1	13	nil	170	13
35	150	nil	240	37	2.4	4.2	1.0	10	12	160	17
(b)	140	nil	190	22	0.26	5.1	trace	4.0	18	170	trace
55	170	----	250	42	1.0	2.3	trace	5.7	50	150	trace
6	230	nil	290	26	0.92	33	11	6.3	nil	280	trace
5	230	nil	300	47	0.50	44	13	5.6	nil	280	trace
10	200	nil	260	38	0.72	20	4.8	4.7	nil	240	<5.0
(b)	225	----	765	130	1	70	23	103	nil	270	65
(b)	225	----	450	80	1	64	20	30	nil	270	41.0
(b)	----	----	1,130	275	30	400	18	50	----	----	18

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
119513	701	1914	do	36.6	P 114	
120595	791	1915	do	70.7	P 114	(a)
120764	806	1915	do	34.1	P 151	(a)
86881	1	1911	Rizal, Las Piñas—San Pedro Tunasan road, Camp Gordon.	46	P 151	
86881	2	1911	Rizal, Las Piñas—San Pedro Tunasan road, Camp Hyson.	146	P 76	
123525	386	1916	Rizal, Las Piñas, poblacion	120	F 15; F 57	nil
123597	392	1916	Rizal, Las Piñas, Pamplona			<5.0
50515	1	1907	Rizal, Fort William McKinley	306		
40608	2	1907	do			
59533	(1)	1908	do			
54655	6	1908	do	260		
57372	7	1908	do	266		
61809	8	1908	do	213		
67895	9	1909	do	229		
70116	10	1909	do	246		
68960		1909	Rizal, Malabon	177	F 10	
114443	512	1913	do	184	F 11	
115193	524	1913	do	143	P 151	
116336	534	1913	do	162	P 76	
117175	547	1913	Rizal, Malabon, Julong-Duhat	143	P 95	(c)
117532	561	1913	Rizal, Malabon, Panjulo	110	P 76	
117673	569	1913	Rizal, Malabon	92.7	P 227	
118666	627	1914	do	113.1	F 6; P 114	
118863	649	1914	Rizal, Malabon, Baritan	143.3	P 76	
119028	665	1914	Rizal, Malabon, Tanyong	82.3	P 114	
119122	675	1914	Rizal, Malabon, Tansuya	91.7	P 114	
124906		1917	Rizal, Malabon, Malabon Sugar Co	183	P 76	nil
72622		1909	Rizal, Mariquina			
74671	1	1909	Rizal, Mariquina, Bayan-bayanan			
74672	2	1909	Rizal, Mariquina, Santo Niño			
74673	3	1909	do			
74674	6	1909	Rizal, Mariquina, San Roque			
74675	7	1909	Rizal, Mariquina, Calumpang			(a)
112498	406	1913	Rizal, Montalban	12	P 53	
112499	423	1913	do	17	P 76	
113542	498	1913	do	167	P 76	
117553	448	1913	Rizal, Morong	88.4	P 114	
117554	502	1913	do	88.4	P 76	
117555	546	1913	Rizal, Morong, Cardona	29	P 182	
121238	826	1915	Rizal, Morong, Calle Sumulong	79.2	P 114	
121540	850	1915	Rizal, Morong	43.6	P 76	nil
121687	868	1916	do	25.6	P 38	5.0
121908	876	1916	Rizal, Morong, Maybancal	87.5	P 38	nil
65576		1909	Rizal, Navotas	162		(c)
116467		1913	Rizal, Navotas (Varadero)			
117895	579	1913	Rizal, Navotas, Tanza	213	F 9; P 95	

[1] Composite source.

[a] Yellow.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
high	345	-------	1,235	165	15	220	40	29	nil	420	420
(b)	275	-------	600	50	3.0	110	24	15	nil	340	170
(b)	290	-------	800	85	6.0	125	21	11	nil	350	230
-------	-------	-------	395	80	0.8	33	5.1	12	-------	-------	15
-------	-------	-------	450	110	0.6	65	22	28	-------	-------	13
<5	250	nil	580	84	0.44	7.0	trace	110	nil	300	25
nil	210	7.0	640	90	1.3	32	16	170	nil	260	5.0
-------	-------	-------	780	-------	-------	-------	-------	330	-------	-------	-------
-------	-------	-------	2,330	-------	-------	-------	-------	1,300	-------	-------	-------
-------	-------	-------	430	70	1.6	29	8.3	49	-------	-------	trace
-------	-------	-------	390	-------	-------	-------	-------	17	-------	-------	-------
-------	-------	-------	380	60	1.1	22	7.8	7.9	-------	-------	8.6
-------	-------	-------	370	70	1.2	26	8.0	11	-------	-------	trace
-------	-------	-------	380	64	2.4	23	7.3	13	-------	-------	trace
-------	-------	-------	435	70	0.8	27	8.0	44	-------	-------	trace
-------	-------	-------	200	-------	-------	-------	-------	16	-------	-------	-------
-------	-------	-------	250	30	trace	6.0	trace	69	-------	-------	trace
-------	-------	-------	320	49	1.6	3.4	trace	59	-------	-------	trace
-------	-------	-------	1,090	94	7.2	15	trace	550	-------	-------	trace
-------	-------	-------	410	66	4.8	13	4.2	115	-------	-------	17
-------	-------	-------	280	54	2.0	2.9	nil	32	-------	-------	14
-------	-------	-------	300	60	trace	6.1	trace	19	-------	-------	trace
-------	-------	-------	270	-------	-------	-------	-------	54	-------	-------	-------
-------	-------	-------	430	40	3.7	5.5	5.8	140	-------	-------	74
-------	-------	-------	370	-------	-------	-------	-------	46	-------	-------	-------
-------	-------	-------	340	68	3.7	4.1	0.36	18	-------	-------	6.5
25	33	20	4,620	17	0.20	930	9.0	2,260	nil	40	170
-------	-------	-------	380	-------	-------	-------	-------	8.9	-------	-------	-------
-------	-------	-------	200	-------	-------	-------	-------	1.6	-------	-------	-------
-------	-------	-------	400	-------	-------	-------	-------	15	-------	-------	-------
-------	-------	-------	380	-------	-------	-------	-------	2.0	-------	-------	-------
-------	-------	-------	250	-------	-------	-------	-------	3.4	-------	-------	-------
(b)	-------	-------	700	-------	-------	-------	-------	140	-------	-------	-------
-------	-------	-------	185	33	nil	39	7	2.9	-------	-------	11
-------	-------	-------	160	32	1.4	32	8.2	6.4	-------	-------	5.5
-------	-------	-------	170	20	2.4	38	7.7	10.0	-------	-------	9.0
-------	-------	-------	330	97	4.4	33	22	9.3	-------	-------	16
-------	-------	-------	320	91	1.6	41	30	2.4	-------	-------	8.2
-------	-------	-------	810	78	5.6	100	36	130	-------	-------	87
(b)	220	-------	330	84	2.0	52	20	8.2	nil	270	trace
-------	220	-------	330	99	1.35	28	trace	7.2	nil	270	trace
-------	230	-------	340	97	0.4	20	19	8.7	nil	280	trace
(b)	234	18	340	107	1.3	35	21	9.2	nil	285	trace
-------	-------	-------	270	47	0.2	3.0	2.8	26	-------	-------	trace
-------	-------	-------	350	-------	-------	-------	-------	27	-------	-------	-------
-------	-------	-------	320	17	1.1	5.5	trace	110	-------	-------	36

[b] Turbid. [c] Brown.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
118141	595	1914	Rizal, Navotas	181.7	P 47	------
118456	609	1914	Rizal, Navotas, Tangos	214	P 227	------
104599	417	1912	Rizal, Parañaque	------	------	------
105142	421	1912	----do	96	P 227	------
105638	424	1912	----do	136	P 170	------
123525	99	1916	----do	274	------	nil
123525	404	1916	----do	148	------	nil
67694	45	1909	Rizal, Pasay	178	P 568	------
68454	------	1909	----do	229	P 151	------
80594	116	1910	----do	227	P 189	------
106255	429	1912	----do	142	P 189	------
112021	116(?)	1913	----do	------	------	------
119808	719	1915	Rizal, Pasay (market)	158.5	P 45	------
119823	438	1915	Rizal, Pasay, San Roque	39.6	P 114	------
119867	732	1915	Rizal, Pasay	68	P 114	------
119983	438-A	1915	Rizal, Pasay, San Roque	74.4	P 57	------
120109	755	1915	Rizal, Pasay, Santol	157.3	P 57	------
120205	------	1915	Rizal, Pasay, Calle Protacio	------	------	------
120206	768	1915	Rizal, Pasay	82.6	P 303	------
120366	------	1915	Rizal, Pasay, Calle Protacio	------	------	------
121718	856	1916	Rizal, Pasay	140.2	P 227	nil
121907	877	1916	----do	139.6	P 76	nil
122147	896	1916	----do	165.5	P 38	nil
122369	914	1916	----do	134.7	P 114	nil
122688	934	1916	----do	182.3	P 76	nil
80095	133	1910	Rizal, Pasig	268	P 38	(e)
120101	753	1915	Rizal, Pasig, Bagong Ilog	34.4	P 227	------
123104	793	1916	Rizal, Pasig	29.9	P 227	5.0
124753	1026	1917	Rizal, Pasig, Santolan	81.4	P 38	nil
98991	380	1912	Rizal, Pateros	35	P 95	------
116975	539	1913	Rizal, Pililla, Kisao	57	F 19	------
120108	763	1915	Rizal, Pililla	30.2	F 9; P 227	------
120143	767	1915	----do	45.7	F 76	------
120278	773	1915	----do	45.4	P 284	------
120359	781	1915	----do	48.8	F 38	------
121373	798	1915	Rizal, San Felipe Neri	263.3	P 19	nil
121503	859	1915	----do	13.1	P 114	nil
121737	863	1916	Rizal, San Felipe Neri, Hagdan Bato	9.1	P 38	nil
121738	872	1916	Rizal, San Felipe Neri	104.5	P 57	nil
121620	P. B.	1915	Rizal, San Juan del Monte	213	------	nil
121838	878	1916	----do	63.7	P 45	nil
121935	885	1916	----do	67.4	P 76	nil
68170	77	1909	Rizal, San Mateo	44	------	(c)
112114	466	1913	----do	266	P 189	(c)
118571	258	1914	Rizal, San Pedro Macati	104.2	F 11; P 76	------
120339	775	1915	----do	105.5	P 76	------
120520	786	1915	----do	91.7	P 76	------
120705	802	1915	Rizal, San Pedro Macati, Guadalupe	108.2	P 114	------

[c] Brown. [e] Green.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
			400	46	1.7	11		120			
			710	22	3.8	27	20	330			44
			360					42			
			880	79	3.8	6.7	2.6	247			48
			770	80	1.8	7.0	1.3	175			75
nil	270	nil	1,100	74	0.44	32	trace	340	nil	330	50
nil	340	nil	670	78	0.20	3.0	trace	100	10	390	27
			4,900			180	68	1,095			
			680	62				210			
			1,070	49	3.6	47	37	320			41
			410	92	2.2	32	12	6.4			6.8
			1,815					870			
clear	220		975	62	trace	50	13	370	nil	270	41
(b)	215		1,475	90	0.4	93	38	600	nil	260	29
(b)	240		395	80	0.4	29	22	24	nil	290	trace
(b)	210		1,250	82	0.2	93	37	560	nil	250	31
nil	250		550	70	nil	7.2	nil	64	nil	270	53
nil	250		500	65	trace	11	trace	55	nil	305	41
nil	250		700	80	trace	29	14	170	trace	305	26
nil	250		400	90	trace	56	23	27	nil	305	nil
	280		460	68	1.1	trace	trace	21	nil	345	27
nil	290	nil	490	80	0.36	trace	trace	49	30	300	trace
15	280	nil	535	78	0.4	7.7	trace	13	18	310	24
nil	250		1,165	90	trace	69	31	455		300	25
nil	220	nil	580	59	0.30	6.2	trace	76	5.9	270	93
			3,600	60	0.8	300	15	2,000			120
(b)	210		395	32	0.5	34	11	44	nil	260	trace
20	240	40	370		1.3	35	12	20	nil	290	trace
<5	210	3.2	340	70	0.72	37	3.6	38	nil	250	nil
(b)			2,400	61	5.8	155	71	1,100			trace
			320	100	2.8	27	12	13			16.8
nil	210		360	105	0.9	36	13	13	nil	260	nil
nil	220		315	82	trace	29	20	10	nil	270	nil
nil	225		355	100	trace	54	16	11	nil	270	trace
nil	200		350	92	trace	27	13	24	trace	240	trace
	58		500	52	0.85	7.5	2.0	79	34	32	155
	180		310	80	0.55	25	trace	9.3		220	trace
nil	170	2.7	290	83	0.4	22	8.7	5.0		210	trace
nil	140		560	40	0.4	4.4	1.3	190	nil	170	17
nil	110		250	15	0.6	9.3	trace	27	16	104	32
nil	166		320	55	0.36	3.7	trace	16	18	190	trace
55	180	nil	300	80	2.2	8.0	trace	7.2	5.9	210	trace
			240	35	0.8	36	7.7	4.5			trace
			295	85	2.8	36	7.6	6.9			trace
			300	40	0.1	0.21	0.02	40			270
nil	265		370	85	trace	36	13	8.0	trace	320	nil
nil	160		300	80	trace	7.0	trace	23	nil	195	nil
nil	65		185	20	trace	trace	trace	11	32	79	trace

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
121029	814	1915	Rizal, San Pedro Macati	106.7	P 76	------
121350	841	1915	Rizal, San Pedro Macati, Masilang	98.1	P 76	nil
124061	1002	1917	Rizal, San Pedro Macati, Zobel building	98.1	P 265	nil
101739	388	1912	Rizal, Taguig	149	P 132	------
104044	394	1912	do	120	P 132	------
97863	352	1912	Rizal, Tanay	19	P 45	------
97864	355	1912	do	49	P 114	------
97869	362	1912	do	34	P 45	------
114276	506	1913	Rizal, Tanay, Barras	91	P 379	------
119789	721	1915	Rizal, Tanay	63.1	P 38	------
119848	729	1915	do	41.5	P 76	------
119883	742	1915	do	45.7	P 76	------
120043	747	1915	Rizal, Tanay, Wawa	139.3	F 49	(a)
88593	272	1911	Rizal, Taytay	155	P 227	------
94640	340	1911	do	98	P 189	------
98157	344	1912	do	242	P 189	------
118477	612	1914	do	48.8	P 132	------
118544	626	1914	do	15.2	P 132	------
118610	632	1914	do	25.9	P 76	------
118707	639	1914	do	25.9	P 132	------
123663	996	1916	Rizal, Taytay, San Juan	29.3	P 57	nil
124325	1005	1917	Rizal, Taytay, Dolores	26.5	P 76	nil
94869	311	1911	Samar, Catbalogan	242	P 114	(c)
117681	441	1913	Samar, Villareal	216.4	P 38	(c)
105977	393	1912	Samar, Wright	311	F 6; P 23	(c)
118476	491	1914	Sorsogon, Bacon	174	P 114	------
119498	692	1914	Sorsogon, Bulan	106.1	F 19	------
119638	702	1915	do	129.2	F 38	------
117451	537	1913	Sorsogon, Casiguran	156	P 76	(a)
117988	560	1913	do	123.4	P 57	------
123020	948	1916	Sorsogon, Gubat	103.6	F 19; P 76	nil
123156	964	1916	do	110.3	F 28; P 114	nil
123227	976	1916	do	134.4	F 23; P 114	nil
123430	981	1916	do	103.9	P 76	nil
120102	715	1915	Sorsogon, Irosin	167.6	P 38	------
120964	770	1915	do	132.6	P 67	------
118526	593	1914	Sorsogon, Juban	159.7	P 45	------
118992	618	1914	do	146	P 30	------
119203	668	1914	Sorsogon, Magallanes	121.9	P 114	------
122286	911	1916	Sorsogon, San Fernando	106.7	F 1,817	------
122722	939	1916	Sorsogon, San Fernando, Buyo	109.7	F 8; P 26	nil
121926	862	1916	Sorsogon, San Jacinto	169.8	F 15	<5.0
122158	891	1916	do	86.9	P 76	trace
10?944	437	1912	Sorsogon, Sorsogon	99	F 95	------
110866	456	1912	do	94	F 57	------
118593	223	1914	Surigao, Butuan	79.2	------	------
120128	636	1915	Surigao, Surigao	135.9	P 88	------
108992	419	1912	Tarlac, Camiling	152	P 95	------

[a] Yellow. [c] Brown.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
-------	190	-------	340	-------	15	2.9	trace	14	6.4	220	15
-------	235	-------	440	82	2.2	35	9.4	15	nil	290	trace
<5	190	nil	290	42	0.16	2.8	1.0	12	14	210	2.1
-------	-------	-------	1,110	91	12	18.8	trace	305	-------	-------	130
-------	-------	-------	1,070	82	1.8	31	5.6	800	-------	-------	155
-------	-------	-------	340	50	4.4	54	21	3.9	-------	-------	11
-------	-------	-------	340	87	4.8	52	19	4.9	-------	-------	11
(b)	-------	-------	370	79	4.0	65	14	4.9	-------	-------	10
-------	-------	-------	380	86	trace	41	35	13	-------	-------	14
-------	250	-------	415	75	nil	46	27	3.0	nil	305	nil
(b)	250	-------	365	70	0.5	70	14	8.0	nil	305	nil
(b)	245	-------	330	77	0.7	82	22	8.0	nil	300	nil
50	220	9	260	80	1.5	32	19	6.7	nil	230	6.0
(b)	-------	-------	660	73	7.2	65	28	32	-------	-------	250
-------	-------	-------	730	95	trace	92	18	170	-------	-------	12
-------	-------	-------	610	63	2.4	61	18	61	-------	-------	170
-------	-------	-------	280	46	3.7	18	1.7	6.5	-------	-------	trace
-------	-------	-------	460	88	0.1	58	19	11	-------	-------	18
-------	-------	-------	660	96	9.7	55	0.24	72	-------	-------	85
-------	-------	-------	370	88	1.7	9.8	5.1	14	-------	-------	3.1
<5	150	14	800	83	0.20	90	11	26	nil	180	-------
<5	310	4.6	390	63	0.20	33	11	5.2	nil	380	nil
(b)	-------	-------	420	38	0.2	1.5	trace	54	-------	-------	34
-------	-------	-------	1,480	19	trace	33	23	290	-------	-------	157
-------	-------	-------	990	-------	-------	-------	-------	150	-------	-------	-------
-------	-------	-------	1,000	62	0.5	25	9.2	380	-------	-------	18
(b)	250	-------	1,800	67	2.5	72	49	760	nil	300	100
nil	255	-------	1,295	75	trace	57	36	380	nil	310	82
-------	-------	-------	330	93	28.0	29	1.2	6.4	-------	-------	10
-------	-------	-------	330	36	trace	43	6.5	43	-------	-------	23
<5	260	29	700	77	0.24	110	17	130	nil	320	12
10	240	20	730	25	0.36	120	16	180	nil	290	17
<5	290	30	840	80	0.32	130	25	210	nil	350	22
<5.0	290	16	530	74	0.5	68	14	76	nil	360	<5.0
nil	280	-------	515	100	0.7	48	49	27	nil	350	31
(b)	355	-------	675	120	3.0	78	37	38	nil	445	86
-------	-------	-------	380	120	5.7	14	1.2	8.7	-------	-------	nil
-------	-------	-------	380	110	20	20	6.0	9.7	-------	-------	nil
-------	-------	-------	1,300	9.7	1.7	50	82	520	-------	-------	52
-------	2,100	310	2,500	93	3.0	450	145	140	-------	2,620	trace
100	340	-------	420	15	-------	42	40	21	nil	420	nil
(b)	740	75	1,030	56	10	125	56	130	nil	900	18
100	370	11	425	31	4.6	60	32	20	nil	455	trace
-------	-------	-------	240	88	4.6	19	10	6.4	-------	-------	79
(b)	-------	-------	420	89	2.8	54	27	9.5	-------	-------	7.0
-------	-------	-------	1,510	60	3.7	40	68	630	-------	-------	500
nil	150	-------	2,570	25	trace	125	76	1,120	nil	180	120
-------	-------	-------	270	27	0.4	23	14	trace	-------	-------	trace

[b] Turbid.

TABLE XV.—*Well waters of*

Laboratory No.	Well No.	Year.	Locality. (Province, town, barrio.)	Depth of well.	Capacity per minute.	Color.
				Meters.	*Liters.*	
110789	451	1912	Tarlac, Camiling	133	P 265	
113292	478	1913	----do	181	P 76	
117689	549	1913	Tarlac, Gerona	159.1	P 132	(c)
116713	509	1913	Tarlac, Tarlac	234	P 265	(c)
80297		1910	Tarlac, Tarlac (municipal well)	64	P 76	(c)
122947		1916	Tarlac, Victoria	75		nil
105742	359	1912	Tayabas, Atimonan	259	P 38	
121225	1	1915	Tayabas, Boac	48.8	P 61	nil
121226	2	1915	----do	55	P 61	(c)
87526	3	1911	----do	47	F 9; P 38	(a)
80450		1910	Tayabas, Gasan	49	F 3.8; P 19	
117938		1913	Tayabas, Hondagua, Manila railroad company.			
80287	178	1910	Tayabas, Lucena	105	F 38	(a)
84983	212	1910	----do	205	F 76	
113237		1913	Tayabas, Lucena, Hospital de Pobres			
114248		1913	Tayabas, Laguimanoc	244		
96819	316	1912	Tayabas, Pagbilao	268	P 76	
120899	799	1915	Union, Agoo	39.6	P 38	
120408	735	1915	Union, Aringay	34.4	P 53	
120493	792	1915	----do	21.9	P 114	(a)
122348	623	1916	Union, Balaoan	269.7	P 38	3.0
118409	576	1914	Union, Bangar	131.1	P 246	
121625	866	1915	Union, Santo Tomas	36.6	F 57	140.0
122308	879	1916	----do	103.6	P 45	nil
119882	699	1915	Zambales, Botolan	75	P 132	
99418	1	1912	Zambales, San Narciso			(a)
99418	2	1912	----do			

[a] Yellow. [c] Brown.

the Philippine Islands—Continued.

Turbidity (SiO_2).	Alkalinity ($CaCO_3$).	Acidity (CO_2).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Chlorine (Cl).	Carbonates (CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).
(b)	--------	--------	290	43	2.0	42	41	4.5	--------	--------	11
--------	--------	--------	110	--------	--------	--------	--------	10	--------	--------	--------
--------	--------	--------	460	52	trace	20	3.5	140	--------	--------	trace
--------	--------	--------	470	94	3.6	28	9.0	81	--------	--------	nil
(b)	--------	--------	345	82	2.8	40	20	16	--------	--------	28
<5	210	nil	450	30	0.40	4.7	3.0	73	nil	260	9.6
--------	--------	--------	490	46	1.6	70	17	60	--------	--------	68
--------	165	--------	255	27	0.1	49	11	11	nil	200	5.3
--------	350	--------	465	11	0.07	trace	5.0	13	nil	430	trace
--------	--------	--------	525	29	3.4	7.3	5.3	28	--------	--------	12
--------	--------	--------	400	66	2.8	26	9.2	31	--------	--------	230
--------	--------	--------	1,100	45	4.5	21	14	245	--------	--------	140
--------	--------	--------	950	25	1.4	4.1	1.1	150	--------	--------	140
--------	--------	--------	1,800	59	1.8	16	3.7	700	--------	--------	260
--------	--------	--------	460	--------	--------	--------	--------	27	--------	--------	--------
--------	--------	--------	1,800	68	trace	190	65	610	--------	--------	110
--------	--------	--------	990	90	3.6	96	51	245	--------	--------	34
--------	325	--------	1,300	67	10	18	45	475	trace	400	trace
nil	300	--------	1,080	12	trace	32	11	400	nil	370	nil
nil	330	--------	870	40	trace	71	24	290	nil	400	trace
5,000	640	--------	980	60	1.5	4.6	9.1	140	29	780	trace
--------	--------	--------	240	40	3.7	51	8.6	5.4	--------	--------	14
--------	320	--------	1,100	22	1.2	trace	12	430	trace	390	trace
65	250	5.4	1,700	40	1.2	165	3.8	815	--------	300	nil
(b)	135	--------	720	60	2.2	93	25	225	nil	165	33
--------	--------	--------	1,100	--------	--------	--------	--------	480	--------	--------	--------
--------	--------	--------	635	--------	--------	--------	--------	190	--------	--------	--------

[b] Turbid.

TABLE XVI.—*Artesian wells of*

Well No.	Location. (Province, town, barrio.)	Date.	Temperature.	Odor.	Turbidity.
			°C.		
	Cebu, Asturias, poblacion	1916	28	Nil	nil
2	Cebu, Balamban, poblacion	1916	31	H_2S	(a)
8	do	1916	29	Nil	nil
1	Cebu, Balamban	1916	28.8	do	(a)
	Cebu, Toledo, poblacion	1916	27	do	nil
	do	1916	28	H_2S	trace
	do	1916	28.5	do	trace
	Cebu, Tuburan, poblacion	1916	29	Nil	(a)
	Laguna, Bay, poblacion	1916	31.7	Hydrocarbons	nil
	do	1916	32.5	do	nil
	Laguna, Calamba, poblacion	1916	29	Nil	trace
	Laguna, Calamba, Canlubang	1916		do	nil
	Laguna, Los Baños, San Antonio	1916	31.8	do	45
685	Laguna, Pagsanjan, town	1916	31	H_2S	nil
703	Laguna, Pagsanjan, Maulaoin	1916	32	do	nil
723	Laguna, Pagsanjan, Buboy	1916	28	H_2S and CO_2	(b)
27	Laguna, Santa Cruz, town	1916	34.5	H_2S	nil
28	do	1916	31.5	do	nil
498	Laguna, Santa Cruz	1916	36	H_2S and CO_2	nil
440	do	1916	38	H_2S	nil
459	Laguna, Santa Cruz, Santo Angel	1916	37.5	do	nil
907	Laguna, Santa Cruz, Umboy	1916	31.5	Nil	slight
	Laguna, Santa Cruz, Patimbao	1916	28.5	do	nil
907	Laguna, Santa Cruz, Umboy	1916	32.5	CO_2	nil
	Laguna, Santa Cruz, town	1916	30.5	Nil	nil
	Laguna, San Pablo, Santa Maria, Magdalena.	1916	29	do	20
	Misamis, Cagayan, poblacion	1916	30	do	nil
	Occidental Negros, Bacolod, poblacion	1917	30	do	nil
	Occidental Negros, Bacolod, Mandalagan	1917	29.5	do	(a)
	Occidental Negros, Bacolod, poblacion	1917	27.8	do	nil
	Occidental Negros, Hinigaran, Aranda	1917	29.2	do	(a)
	Occidental Negros, Hinigaran, Hacienda Guanco.	1917	28.4	do	(a)
889	Occidental Negros, Hinigaran, Paticul	1917	30		
883	Occidental Negros, Hinigaran, Naravis	1917	29.7	Nil	nil
919	Occidental Negros, Isabela, poblacion	1917	28.3	do	trace
	do	1917	29	do	(a)
931	do	1917	29	H_2S	(a)
	do	1917	29	Nil	trace
	Occidental Negros, Saravia, poblacion	1917	28	do	nil
	do	1917	27.5	do	(a)
	do	1917	27.7	do	(a)
	Occidental Negros, Saravia, Tabigue	1917	27.7	do	nil
	Occidental Negros, Saravia, Gahit	1917	28	H_2S	nil
	Occidental Negros, Saravia, poblacion	1917	28	Nil	(a)
	Occidental Negros, Saravia, Alicante	1917	28	do	nil
	do	1917	28		

[a] Nil when drawn.

the Philippine Islands.

Alkalinity.	Acidity.	Iron (Fe).	Chloride (Cl).	Normal carbonates (Na_2CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Total hardness ($CaCO_3$).	Estimated incrustants.	Classification for boiler use.	Colonies per cubic centimeter.	Presumptive test.
470	nil	0.47	150	110	450	12	59	220	Poor	4	Negative.
460	20	2.4	260	nil	560	26	520	510	Bad	9	Do.
400	23	0.7	9	nil	490	9.6	310	360	Poor	----	
550	8.3	1.5	35	nil	670	nil	250	400	do	58	Negative.
430	46	0.07	15	nil	520	18	440	450	Bad	1	Do.
550	33	1.2	150	nil	670	32	330	460	do	5	Do.
550	38	3	380	nil	670	65	340	490	do	12	Do.
460	23	3.7	125	nil	560	80	500	540	do	0	Do.
700	33	0.83	33	nil	850	nil	170	440	do	----	
520	31	0.6	42	uil	630	nil	180	350	Poor	----	
280	15	0.37	9	nil	340	trace	150	220	do	8	Negative.
230	18	0.07	7.2	nil	280	trace	140	190	Fair	17	Do.
400	31	4	41	nil	480	trace	200	----	----	38	Positive.
260	nil	1.1	150	trace	320	100	41	----	----	----	
170	nil	0.25	41	trace	210	16	44	----	----	----	
570	87	4.5	160	ni	700	trace	400	----	----	13	Negative.
350	trace	0.33	47	nil	430	nil	120	----	----	----	
405	----	nil	18	trace	490	nil	110	----	----	----	
360	11	0.17	41	nil	440	nil	82	----	----	----	
400	15	0.5	40	nil	490	trace	74	----	----	----	
370	trace	nil	28	nil	455	nil	94	----	----	----	
300	nil	0.1	11	trace	360	nil	100	----	----	55	Positive.
150	trace	0.25	10	nil	180	nil	79	----	----	11	Negative.
465	27	0.6	62	nil	570	trace	79	----	----	9	Do.
235	11	0.25	13	nil	290	trace	100	----	----	0	Do.
295	51	1.7	24	nil	360	28	200	----	----	10	Do.
310	nil	0.47	32	78	305	nil	135	190	Fair	88	
280	12.5	2.7	5.8	nil	280	trace	----	----	----	1	Negative.
190	17	2.2	8	nil	230	trace	----	----	----	10	Do.
200	17	1.2	3	nil	240	trace	----	----	----	----	
250	40	11	5.7	nil	305	nil	----	----	----	86	Negative.
270	nil	6	260	trace	330	nil	----	----	----	18	Do.
----	----	----	----	----	----	----	----	----	----	45	Do.
290	nil	1	77	trace	250	18	----	----	----	13	Do.
190	33	12	8.3	nil	230	nil	----	----	----	5	Do.
180	25	11	5	nil	220	nil	----	----	----	8	Do.
190	30	11	7.3	nil	230	trace	----	----	----	10	Do.
280	25	4	6.6	nil	280	nil	----	----	----	18	Do.
320	30	2.1	4	nil	390	nil	----	----	----	66	Do.
310	36	3.8	5	----	380	nil	----	----	----	----	
380	20	2.1	6	nil	460	nil	----	----	----	5	Negative.
400	18	0.8	6	nil	490	nil	----	----	----	----	
440	nil	0.4	18	trace	540	nil	----	----	----	----	
320	31	3.7	8	nil	390	nil	----	----	----	4	Negative.
310	----	0.8	11	nil	380	trace	----	----	----	27	Do.
----	----	----	----	----	----	----	----	----	----	2	Do.

[b] Clear when drawn; turbidity develope on standing.

TABLE XVI.—*Artesian wells of*

Well No.	Location. (Province, town, barrio.)	Date.	Temperature.	Odor.	Turbidity.
			°C.		
....	Occidental Negros, Silay, poblacion	1917	28.4	Nil	(a)
....	Occidental Negros, Silay, Mambulac	1917	28.5	....do	(a)
....	Occidental Negros, Silay, Balaring	1917	28.3	....do	nil
....	Occidental Negros, Talisay, poblacion	1917	29.4	....do	(a)
....	....do	1917	29.5	....do	nil
....	....do	1917	29	....do	(a)
....	Occidental Negros, Talisay, Bagaas	1917	....	....do	(a)
....	Occidental Negros, Victorias, poblacion	1917	28	....do	(a)
....	Occidental Negros, Victorias, Viejo	1917	28.9	....do	nil
....	Nueva Vizcaya, Bagabag, poblacion	1917	27.5	....do	nil
....	Nueva Vizcaya, Bambang, poblacion	1917	27	....do	nil
....	Nueva Vizcaya, Bayombong, poblacion	1917	25.8	....do	nil
....	Nueva Vizcaya, Solano, poblacion	1917	27.5	....do	nil
344	Rizal, Cainta	1916	29.3	....do	very slight
121	Rizal, Mariquina, San Roque	1916	28.1	....do	nil
120	....do	1916	28.3	....do	nil
126	Rizal, Mariquina, Santo Niño	1916	28	....do	(a)
127	Rizal, Mariquina, Bayan-bayanan	1916	28.3	....do	nil
....	Rizal, Mariquina, Santa Elena	1916	28	....do	nil
498	Rizal, Montalban, poblacion	1916	28	....do	nil
423	....do	1916	28	....do	nil
233	....do	1916	27.8	....do	nil
101	....do	1916	28	....do	nil
229	Rizal, Montalban, Burgos	1916	28	....do	nil
....	Rizal, Montalban, San Jose	1916	27.5	....do	nil
91	....do	1916	27.5	....do	nil
793	Rizal, Pasig, Bagong Ilog	1916	28.8	....	....
....	Rizal, Pasig, poblacion	1916	28.8	Nil	nil
....	....do	1916	29.5	....do	trace
82	Rizal, San Mateo, poblacion	1916	29.7	....do	nil
77	....do	1916	27.8	....do	nil
111	....do	1916	28	....do	faint trace
250	....do	1916	28	....do	nil
242	Rizal, San Mateo, Guinayang	1916	27.4	....do	nil
466	Rizal, San Mateo, poblacion	1916	29.3	H_2S	nil
243	....do	1916	28.2	Nil	nil
108	....do	1916	28	....do	nil
....	....do	1916	28	....do	(a)
272	Rizal, Taytay	1916	29	....do	nil
340	....do	1916	29	....do	nil
626	....do	1916	29.3	....do	nil
632	....do	1916	29	....do	nil
....	Sorsogon, Bulan, town	1916	34.8	H_2S	nil
....	Sorsogon, Irosin, town	1916	31.2	....do	slight
....	Sorsogon, Masbate, poblacion	1916	30	Nil	(a)
....	....do	1916	29	....do	nil
....	....do	1916	....	....do	trace
911	Sorsogon, San Fernando, poblacion	1916	33	CO_2	(a)
939	Sorsogon, San Fernando, Buyo	1916	31.4	Nil	trace
....	Sorsogon, San Fernando, Batuan	1916	32.2	....do	trace

[a] Nil when drawn.

the Philippine Islands—Continued.

Alkalinity.	Acidity.	Iron (Fe).	Chloride (Cl).	Normal carbonates (Na_2CO_3).	Bicarbonates (HCO_3).	Sulphates (SO_4).	Total hardness ($CaCO_3$).	Estimated incrustants.	Classification for boiler use.	Colonies per cubic centimeter.	Presumptive test.
150	30	3.7	4.5	nil	180	nil	......	......	......	......	
180	27	5	4.5	nil	220	nil	......	......	......	......	
270	12	0.87	130	nil	330	nil	......	......	......	4	Negative.
260	14	1.4	12.5	nil	320	trace	......	......	......	......	
260	20	0.53	12.5	nil	320	nil	......	......	......	......	
240	18	1.6	7	nil	290	trace	......	......	......	4	Negative.
150	56	11	11	nil	180	trace	......	......	......	......	
180	33	5	8	nil	220	trace	......	......	......	4	Negative.
180	7	0.47	6	nil	220	nil	......	......	......	24	Do.
160	32	4.3	12.5	......	......	22	150	170	Fair	......	
140	19	0.13	12.5	......	......	44	150	180	......do	......	
130	5.1	1.7	10	......	......	24	140	150	......do	......	
160	26	0.73	6.3	......	......	20	160	170	Fair	......	
300	14	0.17	170	nil	370	160	230	400	Poor......	17	(?)
530	48	0.45	15	nil	650	trace	160	350	......do	12	Negative.
600	41	0.41	7	nil	730	trace	150	380	......do	174	Positive.
430	92	6	38	nil	520	trace	150	290	......do	18	Do.
140	38	0.17	10	nil	170	trace	52	96	Fair	12	Negative.
250	100	0.2	100	nil	305	100	270	350	Poor......	422	Positive.
210	41	0.33	10	nil	260	trace	118	......	......	(?)	Do.
210	13	0.33	7	nil	260	trace	110	160	Fair	2	Negative.
190	12	0.07	10	nil	230	trace	90	140	......do	1	Do. (?)
200	16	0.57	10	nil	240	trace	96	150	......do	4	Do. (?)
190	85	0.33	11	nil	230	trace	80	140	......do	6	Do. (?)
230	14	0.2	17	nil	280	trace	96	120	......do	2	Do.
200	11	0.23	10	nil	240	trace	92	150	......do	200	Do.
......	......	......	......	......	......	......	......	......	......	......	
360	18	1	10	nil	440	nil	130	250	Poor......	220	Positive.
200	20	1.5	11	nil	240	nil	88	140	Fair	80	Negative.
280	5	0.4	13	nil	340	trace	82	180	......do	15	Do.
270	5	0.57	13	nil	330	trace	82	180	......do	23	Do.
300	40	1.2	12	nil	365	trace	96	200	Poor......	9	Do.
260	37	0.67	9	nil	320	trace	96	180	Fair	18	Positive.
160	26	0.07	8	nil	195	trace	63	110	......do	5	Negative.
280	13	0.92	14	nil	340	trace	91	190	......do	28	Positive.
250	38	1.8	10	nil	305	trace	80	170	......do	95	Do.
240	37	1.2	7	nil	290	trace	80	160	......do	19	Do.
310	46	2.6	24	nil	380	trace	120	220	Poor......	8	Do.
380	12	0.4	23	nil	460	240	130	460	Bad	210	(?)
360	22	0.5	17	nil	440	24	140	270	Poor......	230	Negative.
480	40	0.63	13	nil	590	38	150	350	......do	40	(?)
370	37	0.17	90	nil	450	100	170	360	......do	65	Negative.
320	15	......	820	nil	390	large	280	......	Bad......	......	
410	23	1.7	29	nil	500	53	220	350	Poor......	......	
430	16	1.6	140	nil	525	290	250	540	Bad	29	Positive.
570	23	0.8	43	nil	695	trace	140	360	Poor......	0	Negative.
630	31	3.8	970	nil	770	250	380	690	Bad	0	Do.
3,300	1,100	4.5	220	nil	4,030	trace	1,900	2,600	......do	......	
460	16	2.9	27	nil	560	trace	250	360	Poor......	......	
390	24	2.1	14	nil	475	trace	190	290	......do	......	

[a] Nil when drawn.

APPENDICES

APPENDICES

THE LOCATION OF ARTESIAN WELLS IN THE PHILIPPINE ISLANDS FROM A GEOLOGIC VIEWPOINT[1]

It will be assumed that the reader is conversant with the principles governing the phenomena of artesian wells, and in the following discussion no attempt will be made to consider the numerous factors which control the subsurface accumulation of water under hydrostatic conditions.

The conditions under which water-bearing rocks, like intercalated sandstones and shales, were laid down in the Philippines, where the distribution of land masses is irregular and the interruption of sedimentary processes by vulcanism was frequent, were so variable that no single bed nor any series of beds extends uniformly over great distances. Thus it is not possible here, as it is, for instance, in Australia, to map closely the outcrop of the "intake beds" nor to calculate the depths at which such beds will be encountered over large areas.

It is probable that very often wells will be drilled at towns which need most urgently a supply of potable water, irrespective of the chances of obtaining water. Frequently there will be little choice between different possible locations in a small town, and it may be found expedient to locate the well on the plaza or at some other central point without taking into consideration any other controlling factors. However, where towns are so situated as to include within their area parts of different geologic formations, there may be opportunity to exercise some discretion in choosing a drilling site.

A large proportion of the flowing wells in the Philippines will cease to flow if the casing is continued even a few meters above the ground surface; that is to say, if such wells had been drilled from a slightly higher elevation, it would have been necessary to pump them. It follows that, other things being equal, the lower of two possible sites is preferable. However, the possibility of surface contamination should be kept in mind in this connection. A well on low ground is more often contaminated by surface waters than one on higher ground. It is true also

[1] By Wallace E. Pratt, reprinted from *Phil. Journ. Sci., Sec. A* (1915), 10, 231.

that a well should not be located too near the seashore in an attempt to get it on low ground. Too often in such a location the well encounters brackish water.

Through the coöperation of the Bureau of Public Works the Bureau of Science has had access to drillers' logs for about 700 artesian wells. Samples of the drill cuttings have been submitted for examination in the cases of about half of these wells. These data, and a knowledge of the general geology of the Philippines, are made the basis of the following discussion.

For their consideration in relation to artesian waters the geologic formations of the Philippines may be classed and summarized as shown in Table I.

LITTORAL AND ALLUVIAL DEPOSITS

A large proportion of the population of the Philippines lives in regions in which the land is made up of littoral and alluvial deposits. The important areas of alluvium are found in great structural valleys like the Central Plain of Luzon, the Cagayan Valley in northern Luzon, the Bicol Valley in southeastern Luzon, the Iloilo Plain in Panay, and the Cotabato and Agusan Valleys in Mindanao. The littoral deposits make up the coastal plains which fringe many of the islands, like the plain upon which the town of Cebu is located. The structural valleys have been filled up by loose clays, sands, and gravels carried down from the adjacent highlands by shifting streams and deposited along an ever-advancing shore line. The coastal plains have been built up in the same way; in many cases they rest upon a base of coral reefs, which have grown up offshore from the various land masses. Both the filled structural valleys and the coastal plains combine alluvial and littoral deposits in their structure, since the alluvium carried by streams was deposited largely at the seashore where part of it was worked over again by wave action. In either situation the littoral and alluvial deposits are surprisingly thick; in very few cases have wells passed through them into the underlying formations.

A majority of the wells drilled by the Bureau of Public Works have penetrated these classes of material. A majority also of the successful wells have obtained their water from sands and gravels of littoral or alluvial or combined littoral and alluvial origin. It cannot be said, however, that littoral and alluvial deposits are uniformly productive of artesian water. Such deposits are irregular, and individual beds do not extend over large areas. On the contrary, the formation is characterized by narrow lenses of sand or gravel or clay, such as would be ex-

TABLE I.—*Geologic formations in the Philippines and their relation to artesian-water supplies.*

Formation.	Extent of formation and degree to which it is populated.	Distribution of formation.	Character as a source of artesian water.
Littoral and alluvial deposits	Extensive and densely populated; therefore, important.	Seacoast and low-lying plains; all coastal plains: Central Plain, Cagayan Valley, Bicol Valley, on Luzon; Iloilo Plain, Panay; Agusan and Cotabato Valleys, Mindanao, etc.	Good; a majority of shallow wells in it are successful; source of most of artesian water now obtained, but many unsuccessful wells have been drilled in it.
Coralline limestone	Extensive and densely populated in the Visayans; fairly important.	Seacoast: Cebu, Samar, Bohol, Negros, etc.	Fair only; many wells are dry, some salty.
Volcanic breccia and agglomerates	Fairly extensive, but only fairly well populated.	Mountainous and high plateau areas throughout the Islands.	Fair only in general; some types are commonly water-bearing.
Bedded volcanic tuff	Fairly extensive; densely populated	Southwestern Luzon	Very good; some of the best wells obtain water from this formation.
Tertiary sedimentaries	Extensive; fairly well populated only	Interior and mountainous regions; coal and petroleum-bearing regions generally; Samar.	Bad; dry formation full of salt.
Massive igneous rocks	Extensive, but not usually densely populated.	Interior and mountainous regions generally.	Very bad.
Metamorphic rocks	Limited extent and sparsely populated; unimportant.	Interior and mountainous regions	Bad.

pected in the beds of modern streams or along beaches. It is due to this feature of littoral and alluvial deposits that so often a flowing well will be secured adjacent to a drilled hole which has obtained no water or only pumping water. A striking example is the case of two wells drilled within 50 meters of each other between the Philippine General Hospital and the Bureau of Science in Manila. The first well reached a depth of 178 meters and obtained only 113 liters of water per minute. The second well obtained 322 liters per minute at a depth of only 137 meters. On the completion of the second well work was resumed on the first well in an attempt to get water at the 137-meter horizon, but all efforts to this end failed. Neither of these wells flowed, but numerous experiments have demonstrated that in this class of deposits flowing wells, nonflowing wells, and dry wells may be situated side by side.

As has been said, littoral and alluvial deposits are made up of loosely consolidated sands, clays, and gravels. The loose character of the formation is responsible for the commonly noted phenomenon that in wells situated near the coast line the level of the water in the well varies with the stage of the tide in the adjacent sea. The fresh water in the upper part of the land mass is always percolating through porous beds toward the sea, and in the region of the seashore it is in some measure in a condition of hydrostatic equilibrium with the sea water, which saturates the porous beds outcropping on the sea floor. The rising tide actually increases the hydrostatic pressure on the ground water in the adjacent porous beds. This effect is especially marked where an old coral reef has been included between the deeper beds of the formation, because the loose structure of the coral reef affords unusually free passage for water.

Another factor which must be considered in connection with littoral and alluvial formations is the possibility of obtaining salt water in wells adjacent to the coast. Littoral deposits are contaminated by the salt water in which they were formed. Close to the coast line percolation of the fresh ground water may not have been extensive enough to have removed all the original salt, particularly where the formation contains clay, which is not easily permeable. Salt water is almost inevitably encountered at depth in wells near the coast line. The ground-water circulation appears to be most vigorous at depths generally less than 180 meters. Consequently, if potable water is encountered in littoral or alluvial deposits at depths of from 60 to 150 meters, it is usually advisable to make arrangements to use this water even though it be of limited quantity and require

pumping, rather than to continue drilling in the hope of obtaining flowing water or water in greater quantity at extreme depths. Occasionally, where it has been possible to case out salt water, wells have been deepened and have obtained fresh water at lower levels, but as a rule, fresh water has not been found below salt water.

The discussion of alluvial and littoral deposits and combinations of these two classes of deposits may be extended and applied to intermingled alluvial, littoral, and fragmental volcanic material as well. Volcanic tuffs are often and extensively interbedded with alluvium and with littoral deposits in the Philippines; less frequently volcanic breccias and agglomerates alternate with alluvial or littoral material. Volcanic tuffs, as a matter of fact, usually contain interbedded alluvium, and similarly alluvium usually includes some volcanic tuff. The combinations of these several classes of material yield water about as commonly and under about the same conditions as littoral and alluvial deposits themselves.

CORALLINE LIMESTONE

Coralline limestone is generally dry where it occurs over extensive areas and in thickness. It is so porous and so thoroughly jointed and cavernous that water percolates through it with little hindrance. Only in coralline limestone that is interbedded with impervious beds of clay, marl, or other material is water confined so as to be available under hydrostatic pressure. Fortunately a great deal of the recent coralline limestone in the Philippines is interbedded with impervious material and, therefore, can often be made to yield water. Coral reefs have been found in buried littoral deposits, and in this position were saturated with water under pressure. More commonly coral reefs have been found in deposits of water-laid volcanic tuffs in relations which made the coral reef a natural reservoir for ground water. But the commonest condition under which water has been obtained from coralline limestone is that of interbedded coralline limestone and clayey marl. The thick marl beds are impervious and confine the water in the intervening porous coral-reef members of the series.

Coralline limestone is most abundant in the Visayan Islands, especially in Cebu and Bohol. On both these islands it includes marl beds. Good wells have been obtained in this formation in only about 50 per cent of the trials made. The chance of encountering salt water is great if the well is drilled to a depth which carries it much below sea level. In drilling through

coral, the hole should not advance far beyond the casing, even though the wells may stand up well, and especial watch should be maintained for impervious layers which may act as confining agents.

VOLCANIC BRECCIAS AND AGGLOMERATES

Volcanic breccias and agglomerates, made up of varyingly coarse and fine fragmental material embedded in tuff, are very common in the Philippines. These rocks have usually been deposited on the sea floor and, therefore, have been worked over and roughly stratified by water, but heterogeneous breccias and agglomerates of subaërial deposition are also known. These rocks are found in the immediate vicinities of old volcanoes and along lines of former volcanic activity. Much of the material is indurated and impervious, but an equal proportion, perhaps, is loose and porous.

In massive breccias or agglomerates there is only slight chance of obtaining artesian water, but where the fragmental material has been deposited on a sea floor, and is, therefore, somewhat bedded, artesian water may be obtained. Wells on the southeastern and eastern shores of Laguna de Bay have yielded good flows from this class of rock. There is a considerable area of bedded volcanic agglomerate around the base of Mount Isarog in Camarines which ought to yield water, and likewise in northern Camarines and in Sorsogon there are places at which it is suspected rocks of this nature are water-bearing. On the whole, however, volcanic breccias and agglomerates are rather uncertain territory for the artesian-well driller.

Mineralized water is often encountered in massive volcanic agglomerate. Hot springs and other evidences of solfataric action are associated with these rocks, so that in addition to the possibility of encountering no water there is the further chance that if water is encountered it may be too thoroughly mineralized to be potable.

BEDDED VOLCANIC TUFF

Bedded volcanic tuff is found extensively in southwestern Luzon and has proved to be particularly reliable as a source of artesian water. This tuff has not been indurated nor consolidated through folding processes; it is distinctly bedded and generally porous, but the successive beds are varyingly fine-grained, so that conditions for confining water under some pressure are very good. Many of the wells in the bedded tuff have yielded flows, and a great majority have yielded either pumping

or flowing water. The bedded tuff formation is, perhaps, more uniformly water-bearing than any other of the Philippine rock series.

TERTIARY SEDIMENTARIES

The Tertiary (Miocene) sedimentaries consist of shales, sandstones, conglomerates, and limestones. The formation is encountered in various parts of Luzon; it makes up nearly the whole of the area of Samar; and it is important in Leyte, Cebu, Panay, and in parts of Mindanao. Coal and petroleum are found only in the Tertiary sedimentaries in the Philippines, and the distribution of these minerals may be used as a guide in this connection. The shales and sandstones are made up in large proportion of volcanic material. The series as a whole is indurated and close-grained; consequently it carries but little water. Moreover the fine-grained beds retain a great deal of their original salt content, and this contaminates any water which is obtained from them. Only a small number of wells have penetrated the sedimentary series, and only a small proportion of these have been successful. Where this series of beds constitutes the underlying formation, a serious effort should be made to obtain potable waters in the surface alluvium if it is available. Deep wells are to be undertaken only as a last resort.

It must be admitted that some artesian water has been obtained from the sedimentary rocks, but the flows are invariably small, and no eminently satisfactory wells have been drilled into the formation. The sandstones and the conglomerates yield water under favorable conditions, but even these rocks are too dense to be of great promise. The limestone members of the series are very cavernous and jointed, and water percolates through them readily. The lower limestone, which is very close to the base of the sedimentary series, is undoubtedly the most important possible source of artesian water in this formation. At its outcrop this limestone is corroded and jointed until it is a very porous rock. The sedimentary series is usually found flanking the cordilleras and dipping away from them, so that very often this basal limestone is exposed in a region of heavy rainfall and lies at an angle which accelerates the percolation of water along it. If the limestone in this relation were penetrated by a well, it ought to yield water copiously. The difficulties are that the basal limestone is thin, discontinuous, and broken by faulting; that inasmuch as its porosity in surface exposures is due largely to solution, the limestone may not be

porous below the permanent level of ground water; and finally, that its stratigraphic position is such that it is commonly too deeply buried, except in mountainous and consequently uninhabited regions, to be accessible by drilling. The conditions afford a chance, however, which should be tested when opportunity presents.

MASSIVE IGNEOUS ROCKS

Massive igneous rocks abound in all of the truly mountainous portions of the Philippine Islands. Igneous rocks, wherever present to the exclusion of other rocks, constitute the formation least favorable to the accumulation of potable artesian water. They are impermeable to water because of their dense nonporous texture and the absence of bedding planes. It is generally immaterial in this connection whether the igneous rock is of the deep-seated, holocrystalline type, such as the diorites, gabbros, peridotites, and occasional granites, or is one of the surface lava flows, such as the widely distributed andesites and less common basalts, rhyolites, and dacites, although infrequently solidified lava flows are so vesicular and porous as to be permeable to water. Very rarely do common igneous rocks yield water in quantity. No Philippine wells have encountered water in massive igneous rocks, although a dozen, perhaps, have been drilled into them. Minute quantities of water are contained along fractures and joints in igneous rocks, and often mineralized water is encountered in the occasional veins and shear zones; otherwise the rocks are almost invariably dry. Obviously, therefore, igneous rocks are to be avoided in choosing sites for artesian wells.

METAMORPHIC ROCKS

Metamorphic types of rocks are represented in the Philippines principally by schists, with subordinate gneisses and marbles. Because of their dense nature metamorphic rocks are not common sources of artesian water. In the Philippines they are of limited distribution and consequently unimportant; as yet no wells have been drilled into them. Water might be obtained from buried marble, which is often cavernous, but schist and gneiss would probably be found to be dry.

Schists and gneisses, together with massive igneous rocks, are the basal formations in the Philippine rock series and will, therefore, be encountered ultimately in practically any locality in the Islands if the drilling proceeds to a sufficient depth. Since they are devoid of water, no attempt should be made to continue drilling once these formations are encountered.

THE CHEMICAL PURIFICATION OF SWIMMING POOLS [1]

The purification of swimming pools has long been the subject of much study, and a vast literature has been developed concerning it. Many methods have been suggested, notably filtration, sterilization with ultra-violet rays, and the use of ozone, copper sulphate, liquid chlorine, and the hypochlorites of sodium, magnesium, or calcium. Although these methods, or combinations of two or more of them, have been found satisfactory under most conditions, great discrepancies exist in the results recorded. In spite of the fact that there are many factors influencing the purification of swimming pools, many experimenters have treated their particular problems as though they were of general application; hence has arisen much difference in opinion concerning the relative merits of different purifying agents, amounts necessary for efficient purification, methods of application, and the like. In many cases too little attention has been paid to important factors such as quality of water, temperature of pool, number of persons bathing, turbidity and the like to enable general conclusions to be drawn from the results of different workers. The treatment that is highly efficient for one water under certain conditions may fail utterly for a different water under slightly changed conditions.

Of the methods mentioned, the use of chlorine either as liquid chlorine or as a hypochlorite is probably the most widely practiced, and because of their cheapness and because of the ease with which they can be administered, hypochlorites are employed more than liquid chlorine.

The problem of maintaining a swimming pool in Manila in a sanitary and attractive condition is rather complicated. The water from the municipal supply is always slightly turbid, so that the bottom of a pool is generally invisible. This turbidity not only makes a pool unattractive and increases the danger from accidental drowning, but also militates against the action of disinfectants. The temperature (27° C. to 30° C.) is an added factor, as it is nearer the bacterial optimum than that of typical United States installations, and bacterial growth is correspondingly stimulated.

[1] By Geo. W. Heise and R. H. Aguilar, abstracted from *Phil. Journ. Sci., Sec. A* (1916), 11, 105–123.

Obviously filtration should be employed as a preliminary measure in the treatment of waters of the kind described; however, the lack of filtration facilities and the desirability of improving the sanitary condition of the local installations as rapidly as possible made it advisable to see what could be done with chemical methods of purification alone. Three pools were accordingly kept under observation.

When water was left untreated in the local swimming pools, the bacterial count invariably reached enormous figures about the second day, and organisms of the *B. coli* group were practically always to be found in 1 cubic centimeter water samples after the first day. The usual chemical analyses gave little indication of this state of affairs. A slight sedimentation occurred during the first day or two in which the water was used, leading to a decreased turbidity and corresponding fluctuations in oxygen consumption and chloride content. Differences during the week in total solids and alkalinity, if any, were too slight to be of significance; neither chlorides nor oxygen consumed showed the steady increase that might have been expected; turbidity, after the initial drop, remained practically constant.

The use of copper sulphate as a disinfectant both for public water supplies and for swimming pools has been frequently recommended.[2] For example, Thomas,[3] in a recent article, showed that a greater degree of bacterial purification had been effected in a swimming pool with daily additions of 0.4 part per million of copper sulphate than had previously been accomplished with a single addition of 2.5 parts per million of "hypochlorite" [0.8 (?) part of available chlorine], and he concluded that the copper sulphate method was cheaper and more effective and was further superior to hypochlorite treatment because it caused no odor and was not irritating to the eyes. Unfortunately the author gives no data concerning the chemical quality of the water used nor the exact strength of hypochlorite employed. The water was filtered and refiltered, and alum was used as coagulant. As the author points out, the coagulation with alum and subsequent filtration removes the carbonates and bicarbonates that would otherwise hinder the action of copper sulphate.

Our results with copper sulphate show clearly the unsuitability of this method to a water high in substances that react with a copper salt. The test was conducted for two weeks, 1 part of crystalline copper sulphate per million parts of water being

[2] For partial bibliography see Manheimer, *Publ. Health Rep.* (1915), 30, 2796.

[3] *Journ. Ind. Eng. Chem.* (1915), 7, 496.

employed during the first week and 2 parts per million (with fresh water) during the second. In neither case was an effect on the bacterial content apparent after the first day, and long before the end of the week the colony count had reached an enormous figure, the copper sulphate seemingly exercising not the slightest inhibiting effect.

The chemical analysis of the water showed little or no variation. Upon addition of copper sulphate the turbidity of the water increased greatly, owing to interaction with the bicarbonates present and subsequent precipitation of hydroxides and carbonates of copper, calcium, or magnesium. This action would account for the removal of copper sulphate and its failure as a germicide in this series of tests. Owing to the turbidity resulting from its use and to the lack of efficient sterilizing action, it is apparent that, without filtration, the use of copper sulphate is not to be recommended for water similar to the one under observation.

A number of attempts were made to secure adequate purification with chloride of lime, different quantities being used each week.

The first attempt with chloride of lime was made with an addition of 0.5 part of available chlorine[4] per million parts of water. The effect on the bacterial content was apparent for only one day, after which the count was excessive and *B. coli* appeared. No better results attended the addition of 1 part per million, and only with an addition of 2 parts per million could an appreciable effect on the bacterial content on the second day be ascribed to the chemical added. After the second day the bacterial increase proceeded unchecked. In none of these cases was the effect on the chemical constituents great enough noticeably to affect the alkalinity or total solid content of the water.

It might be well to note parenthetically that, although the last-mentioned concentration is far in excess of that generally employed for purification, there was no complaint from users of the pool, except in one case, where a few people complained of irritations of the eyes and of the mucosæ of nose and throat. In this instance it was shown that the trouble was due to careless and improper administration of the disinfectant, which allowed undissolved lumps to get into the tank. The odor was strong and persisted for days, but was not sufficiently disagreeable to be a real drawback to the use of hypochlorite.

[4] All hypochlorite used was analyzed with arsenious acid, using starch-potassium-iodide paper as indicator.

The chlorination having failed to give the desired results, an attempt was made to study in detail the causes of the failure and to overcome the difficulties involved.

It was noticed that, in general, the city water showed no trace of "free chlorine" when it left the mains, as determined chemically by acidifying 200 cubic centimeter samples of water and adding a drop of methyl orange,[5] the presence of chlorine being indicated by the bleaching of the indicator. This result was rather surprising, since the water arrived at the swimming pools probably within three, almost certainly within five, hours after chlorination had taken place. Moreover, in spite of the relatively large additions of chloride of lime to the swimming pools, all trace of "free chlorine" was lost, usually within twenty-four hours.

A laboratory study of the decomposition of a clear (filtered) solution of chloride of lime added to (unchlorinated) city water gave the results indicated in Table I.

TABLE I.—*Decomposition of chloride of lime in water.*

Minutes.	Available chlorine in parts per million.
0	0.8
2	0.6
30	0.3
120	0.1 (?)

From the foregoing it is apparent that the chloride of lime lost its effective strength very rapidly and that in two hours its concentration had fallen below 0.1 per million. Just what is the minimum concentration of chlorine that will keep water free from dangerous organisms is not known; certainly it cannot be much less than the concentration mentioned above.

The destruction of hypochlorite must be due either to spontaneous decomposition or to interaction with substances dissolved in water. Hypochlorites decompose, even in the dark,[6] with measurable velocity. The reaction is greatly accelerated by light,[7] especially by the visible and ultra-violet rays, and by heat. The temperature of a bath, therefore, becomes a matter of no small importance in studying purification of water with hypochlorite, and the amount of daylight falling on a pool may greatly affect the rate at which hypochlorite disappears.

The interaction of chlorine with substances dissolved in water

[5] Winkler, *Zeitschr. f. angew. Chem.* (1915), **28**, I, 22.
[6] Bhaduri, *Zeitschr. f. anorg. Chem.* (1897), **13**, 385.
[7] Lewis, *Journ. Chem. Soc.* (1912), **101**, 2371.

has been much studied in recent years.[8] The phenomenon is generally associated with a high organic content in water. A large amount of "free chlorine" disappears immediately, after which decomposition proceeds more slowly, but does not reach equilibrium for a long time. The amount of chlorine consumed appears to be dependent on the concentration in which it is added; the more hypochlorite added, the more will be decomposed in a given time. The reaction proceeds more rapidly at high temperature than at low.

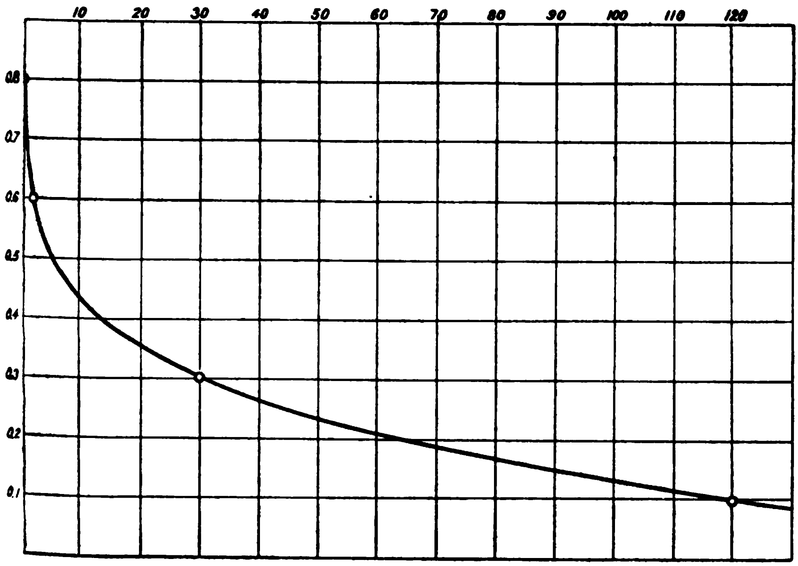


FIG. 2. Decomposition of calcium hypochlorite in water.

Many substances are known [9] to effect the chlorine consumption, notably albumin and its decomposition products, urea, glycocol, peptone, asparagin, and the like. We have determined the chlorine-consuming power of a number of different substances, using the following method:

Two hundred cubic centimeter samples of water, or else the substances under examination dissolved in 200 cubic centimeters of distilled water, were placed in glass-stoppered bottles. To each sample a known excess of clear (filtered) calcium hypochlorite solution was added. The bottle was stoppered and al-

[8] Cf. Glaser, *Arch. f. Hyg.* (1912–13), 77, 165; Hairi, *Zeitschr. f. Hyg.* (1913), 75, 40.

[9] Cf. Elmanowitsch and Zaleski, *Zeitschr. f. Hyg.* (1914), 78, 473; Hairi, ibid. (1913), 75, 46.

lowed to stand at room temperature (30° C.) for two hours in the diffused daylight of the laboratory. After digestion with hypochlorite, 2 cubic centimeters of 10 per cent potassium iodide solution and 2 cubic centimeters of 25 per cent phosphoric acid were added to each sample, and the liberated iodine was titrated with 0.02 *N* sodium thiosulphate solution, starch being used as an indicator.

The differences in chlorine consumption are shown in Table II.

TABLE II.—*Chlorine-consuming power of different substances.*

Substance.	Chlorine added.	Chlorine consumed.	Chlorine consumed per liter.	Remarks.
	mg.	*mg.*	*mg.*	
Distilled water	6.5	0.15	0.75	
Reservoir water (unchlorinated)	6.5	0.2-0.5	1.0-2.5	Varies from day to day.
Tap water (chlorinated)	6.5	0.2-0.6	1.0-3.0	Do.
Artesian well water	1.0	0.24	1.2	Bureau of Science well.
Sea water	6.5	0.75	3.75	From aquarium.
200 cubic centimeters distilled water:				
Plus 0.0025 gram oxalic acid	6.5	0.28	1.4	
Plus 0.005 gram oxalic acid	6.5	0.7	3.5	
Plus 1 cubic centimeter urine	6.5	4.4	22.0	
Plus 0.5 cubic centimeter ± sweat	6.5	5.6	28.0	
Plus 0.5 cubic centimeter saliva	3.4	2.0	10.0	

It is significant that the substances given off from the human body cause the consumption of relatively large amounts of chlorine. This emphasizes the necessity of personal cleanliness on the part of the users of swimming pools if the purification of tank water by means of chlorine is to be successful. A thorough bath with soap should be taken before the pool is entered to remove all body products so far as possible, not only to avoid introducing into the water substances noxious per se, but in order to prevent the destruction of the hypochlorites to which the purifying action is due.

There are, then, two distinct actions or effects: the first, the germicidal action of chlorine or hypochlorites; the second, the specific interaction between the chlorine and the substances in water. There is evidently a minimum concentration below which effective purification does not occur; if this is reached in a short time, purification will not be adequate or lasting in its effect. It thus becomes necessary to maintain at all times in the water of a swimming pool an excess of "free chlorine" sufficient to keep up effective purifying action.

With these conditions in mind, the purification of a swimming

pool becomes a comparatively simple matter. A relatively small amount of hypochlorite will effectively purify the water, after which it becomes necessary to keep the bacterial content within safe limits by means of repeated additions of disinfectant. That this is true is evinced by the results obtained during a series of tests in which chloride of lime was used in quantities representing a daily addition of 0.5 part of "available chlorine" per million parts of water. Throughout this series the bacterial content was kept below 200 and no *B. coli* was found. In all cases the water remained in the pools for two weeks and was safe during the entire period. That there was no cumulative effect and that there was no large excess of chlorine at any time were shown by omitting chlorination for a single day, when the bacterial content immediately increased to dangerous proportions. It took more and more chlorine to produce the same effect as time went on; therefore it became advisable to change the water after about ten days or two weeks, even under the unfavorable circumstances existing in Manila; and if the water be changed weekly, the danger of contamination is very slight.

An attempt made to reduce the quantity of hypochlorite to 0.25 part of available chlorine per million resulted in adequate sterilization of one swimming pool, but a decidedly unsatisfactory state of affairs in another. The former pool was used by more bathers than the latter, but the apparent anomaly was explained by the fact that the second pool was exposed to direct sunlight at certain hours of the day, which decomposed the hypochlorite and subsequently permitted bacterial infection.

It is doubtful if such high concentrations of hypochlorite as those used in Manila would be necessary under average conditions. In addition to the poor quality of the water, the added effects of excessive temperature (almost 30° C.) and of light must be taken into account. Even in the tanks under observation, where conditions were fairly uniform, each case required special treatment. The best-lighted tank required greater additions of chlorine to maintain an excess of disinfectant than did the others; while in the most poorly lighted tank the decomposition rate of hypochlorite was also the lowest. This furnishes explanation for the fact that the treatment with 0.5 part of chlorine, found necessary in one tank, was greater than the requirement for another, while the same treatment in the third caused numerous complaints of excessive and disagreeable odor.

In disinfecting municipal water supplies or sewage there is a certain quantity of contaminating material present; once this is destroyed or removed, there is usually no further influx of

noxious matter. Glaser,[10] in contradiction of the findings of Grether,[11] concluded that a single addition of disinfectant is as efficaceous as the same amount added at intervals in smaller quantities. His results may be correct for ordinary water or for sewage, but it is obvious that different conditions obtain for swimming pools, where the contaminating substances are being continually added. In the latter case the periodic addition of chlorine in small quantities, but sufficiently great to effect purification, is not only preferable, but even necessary, to provide adequate protection to people using the pool. The fractional addition has the further advantage that the objectionable features of high dosage (odor, irritation of mucosæ, and the like) are largely eliminated.

Obviously the water in a swimming pool should be as clear as possible, not only because clear water makes a pool more attractive and lessens the danger of accidental drowning, but also because it is more susceptible than turbid water to the disinfecting action of chlorine. Therefore water should be subjected to filtration, with or without coagulation, wherever practicable. Aside from its coagulating effect, the action of alum is beneficial in that it reacts with bicarbonated waters in such a way that the action of chloride of lime or copper sulphate is interfered with as little as possible.

SUMMARY AND CONCLUSIONS

The chemical purification of swimming pools has been studied with special reference to the action of copper sulphate and chloride of lime.

The work was done on water that was turbid, high in bicarbonate alkalinity, and bacteriologically unsatisfactory.

Copper sulphate was found unsuited to a water of the type used.

As much as 2 parts per million of available chlorine, administered as chloride of lime and at a single dose, failed to keep the bacterial content of the water within safe limits due to the rapid disappearance of available chlorine from the water. It was only with daily additions of chloride of lime that adequate purification resulted. With this procedure, however, it was found possible to keep a pool bacteriologically clean for two weeks without change of water. There were noted no objectionable features arising from the large quantities of disinfectant added.

[10] *Arch. f. Hyg.* (1912), 77, 279.
[11] Ibid. (1896), 27, 189.

(daily additions of 0.5 part of available chlorine per million parts of water). The advantages of the periodic administration of hypochlorites in small quantities over the addition of the same total amount at a single dose are discussed.

The factors influencing chlorine consumption and the chlorine-binding power of various substances were studied. The temperature of the water and the amount of light a pool receives greatly influence the decomposition rate of hypochlorites. Body products have an especially great binding power for chlorine, a fact that emphasizes the need of great personal cleanliness among users of swimming pools.

Determinations of dissolved chlorides or of oxygen consumption give little or no indication of the purity of swimming-pool water. The tests that apparently give the most information are determinations of available chlorine and of chlorine-consuming capacity.

In the purification of the water of swimming pools each case should be considered as a separate problem, since the procedure adapted to one may be entirely unsuited to another. Chemical study is as necessary as bacteriological to obtain the best results. The minimum quantities of hypochlorites necessary to maintain an excess of available chlorine should be first established by experiment, and these quantities should be administered at short, regular intervals. Once the dosage proper for ordinary circumstances is known, it becomes an easy matter to keep a pool in sanitary condition.

REPORT ON CERTAIN METHODS OF STERILIZATION OF WATER CONTAINERS

The autoclave method of sterilizing with steam the demijohns and corks used in certain local artesian water distribution companies has not been satisfactory. The boilers used were too small to maintain the necessary temperature and pressure, and insufficient time was allowed for adequate sterilization, even had the necessary temperature been reached. It is doubtful whether sterilization could be effectively accomplished with steam at sufficiently low cost to ensure the companies a margin of profit at the existing prices for artesian water.

The following methods were introduced into one of these plants, and supervision was maintained until the manner of operation was such that success was automatically assured.

STERILIZATION OF CORKS

The corks are boiled in water for ten minutes. They are kept in a 0.2 per cent solution of formaldehyde until ready for use. Just before insertion in the demijohn, they are rinsed with fresh water from the filling spout.

STERILIZATION OF DEMIJOHNS

The demijohn, as it comes from the consumer, is taken to the sink. Here it is closed with a cork (preferably of universal size, with easy-gripping handle), and the outside is scrubbed with soap and water. As far as possible, the water for the scrubbing is supplied by the overflow from the filling stand. After scrubbing, the demijohn is showered with fresh water from the reserve water tank, in which a circulation is thus maintained. The cork is then removed and the demijohn is taken to a tank (*A*). Here the inside is rinsed with hot lye solution, kept at a temperature of 45° C. by a closed steam coil. Thence it passes to a tank (*B*), where it is rinsed twice with hot water, also kept at 45° C. by a closed steam coil. It now goes to the third tank (*C*), where it is filled with chloride of lime solution (two pounds to approximately a cubic meter of water, unheated except incidentally by the warm empty demijohns from tank *B*. After remaining in the chloride of lime solution for ten

minutes, the demijohn is taken to the filling stand. Here it is first rinsed by inversion over a fountain spray, with occasional turnings to assure thorough treatment. The demijohn is then filled as usual from the filling spout, after which a boy, with rubber gloves, inserts the sterilized and rinsed cork, as described under sterilization of corks. The demijohn is now ready to receive the paper cap and sealing wax, after which it is ready for transportation to the consumer.

NOTES

Following the plan outlined above, the demijohn never touches the floor from the time it is scrubbed until after it is corked.

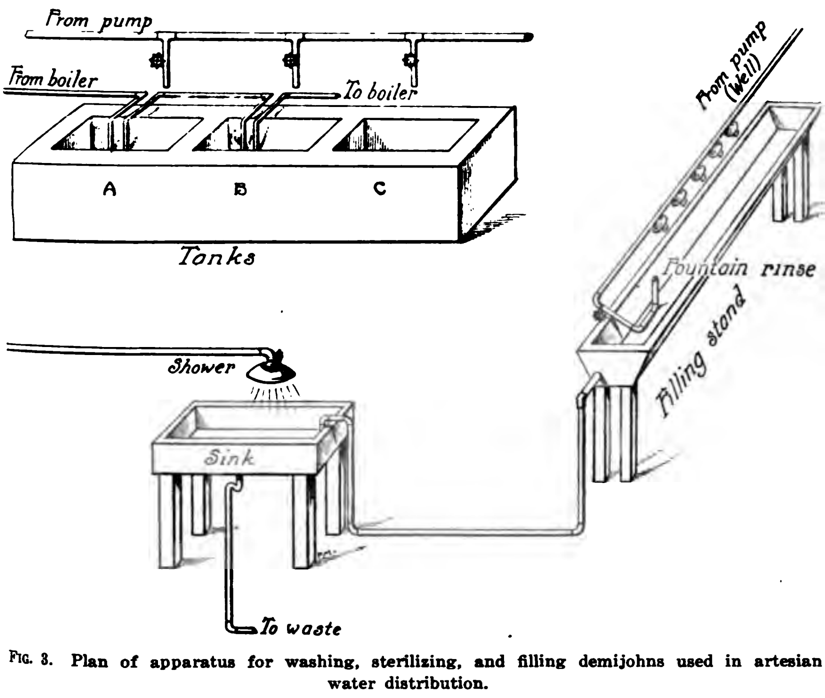


FIG. 3. Plan of apparatus for washing, sterilizing, and filling demijohns used in artesian water distribution.

The idea of sterilization with potassium permanganate was abandoned, as the process was tedious, disagreeable to the operators, and, under present conditions, expensive.

The chloride of lime bath is changed twice a day, with a daily output of from three to four hundred demijohns. The lye tank is refilled daily, the rinsing tank twice a day.

The filler and rinsing spouts are provided with half-throw cocks, instead of ordinary valves, to economize time.

The three tanks are provided with overhead connections to fresh cold water, which may be used for filling the tanks, renewing rinse water, etc.

RESULTS

The methods outlined have effected economies in fuel, time, water, and chemicals. The time now necessary for a demijohn to make the complete cycle of the process is about fifteen minutes.

The quality of the product obtained is satisfactory. Twenty-four hour counts made September 20 on two demijohns selected at random showed 4 and 40 colonies per cubic centimeter, respectively. Similar counts made on two samples submitted to this Bureau on September 26, after the last type of shower-rinse had been adopted, showed 4 and 20 colonies, respectively. Presumptive tests for *B. coli* gave negative results in all four cases.

BUREAU OF SCIENCE DIRECTIONS FOR THE COLLECTION AND TRANSMISSION OF WATER SAMPLES

The following directions have been prepared by the Bureau of Science for general distribution to the public:

Before requesting a water analysis, it is well to consult the District Health Officer or District Engineer. Furthermore it is advisable to communicate with the Bureau of Science, as it is possible that a reliable analysis of the source has been already made and that the information desired is already on file.

Whenever possible, leave the taking of samples of water to the District Health Officer, the District Engineer, or other person qualified to do such work. In this way unnecessary analyses will be eliminated, undue expense will be avoided, and the analyses will be easier to interpret. Remember that the Bureau of Science can determine only the condition of a water as it arrives at the laboratory; if a sample is incorrectly taken, if it is too old when it reaches the laboratory, or if necessary information regarding the source is withheld or is inaccurate, the results of an analysis will be misleading.

QUANTITY OF WATER REQUIRED FOR ANALYSIS

The minimum quantity necessary for making the ordinary physical, chemical, and microscopical analyses of water or sewage is 2.5 liters; for the bacteriological examination, 100 cubic centimeters. In special cases larger quantities may be required. For a complete mineral analysis, five liters should be sent.

BOTTLES [1]

When possible, obtain bottles directly from the Bureau of Science or through the Bureau of Health or Bureau of Public Works. These bottles are properly cleaned, sterilized, and packed in suitable containers for shipment.

The bottles for the collection of samples shall have glass stoppers, except when physical or microscopical examinations only are to be made. Pottery jugs or metal containers shall not be used.

Sample bottles shall be carefully cleansed each time before

[1] The greater part of the material under this head and all under Time Interval Between Collection and Analysis is quoted verbatim from Standard Methods for the Examination of Water and Sewage (1915), 1–2.

using. This may be done by treating with sulphuric acid and potassium bichromate or with alkaline permanganate, followed by a mixture of oxalic and sulphuric acids, and by thoroughly rinsing at least four times with water and draining.

When clean, the stoppers and necks of the bottles shall be protected from dirt by tying cloth and thick paper over them.

For shipment bottles shall be packed in cases with a separate compartment for each bottle. Wooden boxes may be lined with indented fiber paper, felt, or some similar substance or shall be provided with spring corner strips to prevent breakage. Lined wicker baskets also may be used. Bottles for bacteriological samples shall be sterilized.

TIME INTERVAL BETWEEN COLLECTION AND ANALYSIS

Generally speaking, the shorter the time elapsing between the collection and the analysis of a sample the more reliable will be the analytical results. Under many conditions analyses made in the field are to be commended, as data so obtained are frequently preferable to those made in a distant laboratory after the composition of the water has changed en route.

The allowable time that may elapse between the collection of a sample and the beginning of its analysis cannot be stated definitely, as it depends upon the character of the sample and upon other conditions, but the following may be considered as fairly reasonable maximum limits under ordinary conditions:

Physical and Chemical Analysis.

	Hours.
Ground waters	74
Fairly pure surface waters	48
Polluted surface waters	12
Sewage effluents	6
Raw sewages	6

Microscopical Examination.

	Hours.
Ground waters	72
Fairly pure surface waters	24
Waters containing fragile organisms	immediate examination.

Bacteriological Examination.

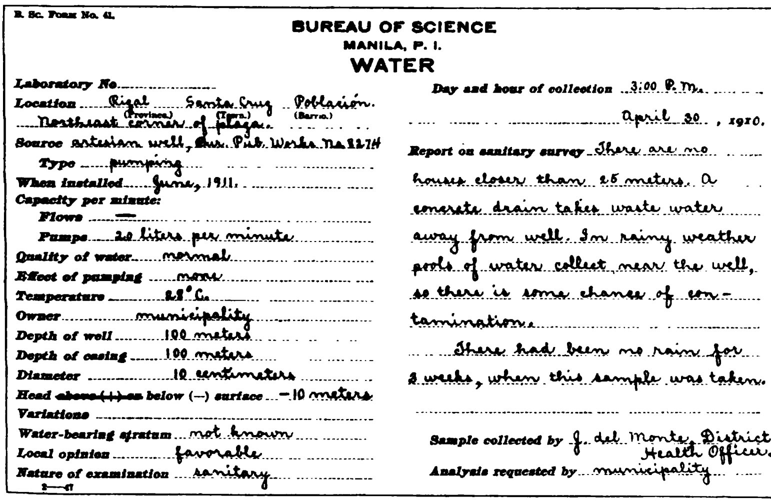
	Hours.
Samples kept at less than 10°C.	6

COLLECTION OF SAMPLES

Rinse the sample bottle several times with the water to be examined, the last time filling the bottle completely before draining. Then fill the bottle and insert the stopper firmly, leaving

a very small air space between the surface of the water and the stopper. A piece of cloth or thick paper should be tied over the stopper and neck to insure cleanliness and security.

The sample submitted for analysis should be a representative one. Thus, if the water is from a pumping well, house connection, or any piping system, the water should be allowed to flow long enough to clean out of the small pipes any accumulation of rust or sediment, as well as the water that has been in contact with the pipe for some time. If taken from a surface well or surface stream, the sample should be taken from a depth sufficient to avoid both surface scum and bottom mud. If taken from a spring, the water should be sampled, whenever possible, where it leaves the water-bearing stratum.



B. Sc. Form No. 41.

BUREAU OF SCIENCE
MANILA, P. I.
WATER

Laboratory No. ....

Location Rizal (Province) Santa Cruz (Town) Población (Barrio.)
Northeast corner of plaza.

Source artesian well, Bur. Pub. Works No. 1274

Type pumping

When installed June, 1911.

Capacity per minute:
Flows —
Pumps 20 liters per minute

Quality of water normal

Effect of pumping none

Temperature 28° C.

Owner municipality

Depth of well 100 meters

Depth of casing 100 meters

Diameter 10 centimeters

Head ~~above (+) or~~ below (—) surface −10 meters

Variations ....

Water-bearing stratum not known

Local opinion favorable

Nature of examination sanitary

2—41

Day and hour of collection 3:00 P. M. April 30, 1910.

Report on sanitary survey There are no houses closer than 25 meters. A concrete drain takes waste water away from well. In rainy weather pools of water collect near the well, so there is some chance of contamination.

There had been no rain for 2 weeks, when this sample was taken.

Sample collected by J. del Monte, District Health Officer.

Analysis requested by municipality

FIG. 4. Bureau of Science form No. 41 properly filled out.

DATA ACCOMPANYING SAMPLE

Of great importance, also, are the general data relating to the conditions of the source and its surroundings. These data are listed on one side of the Bureau of Science water analysis card (Form No. 41). A copy of this form, properly filled out, is shown in fig. 4.

Most of the data requested need no explanation. A few, however, deserve special emphasis.

1. Location. This should be stated as fully and as accurately as possible. A properly stated location should be complete enough to prevent the slightest possibility of confusion with any other point in the vicinity.

2. Quality of water. Any marked color, odor, turbidity, or

other abnormal characteristic should be noted. If the water is normal when drawn, but develops turbidity, color, or odor on standing, a statement of these changes should be made.

3. Local opinion. What do people in the neighborhood think of the water? In case medicinal or other properties are ascribed to it, these should be stated.

4. Nature of examination. State the purpose for which the analysis is desired, such as "for boiler purposes," "for potability," etc.

5. Report on sanitary survey. This should include all data relating to the surroundings of the source that might have affected the quality of the water at the time of sampling or that might affect it in the future. Information on the following points is especially valuable:

a. Distance and relative number of nearest dwellings, outhouses, etc.

b. Condition of immediate surroundings. Is adequate drainage provided for waste water, or does it accumulate near the source, possibly contaminating it? Are washing, bathing, etc., carried on nearby? Are pigs or other animals allowed to come near the source?

c. Topography. Is the source lower or higher than its surroundings? Is it liable, therefore, to be contaminated by surface run off? Are there any other topographic features that might affect the water?

d. Nature of soil and subsoil.

e. Weather conditions prevailing when sample was taken.

f. Variations in quantity and quality of water with season, weather changes, tide, etc.

The foregoing directions for sampling water are primarily for potability tests. For samples for technical purposes, such as suitability for boilers, etc., the data required under "(5) Report on sanitary survey," may be disregarded. However, it is very important that a representative sample be secured, and the container should be thoroughly cleaned and well stoppered.

Fig. 1. Flowing well, Malolos, Bulacan Province.

Fig. 2. Surface well lined with earthen tile curbing, near San Miguel, Bulacan Province.

PLATE II.

Fig. 1. Open well, Pasay.

Fig. 2. Open well near municipal building, Taytay.

PLATE III.

PLATE IV. MANDURIAO ARTESIAN WELL, ILOILO. A SATISFACTORY TYPE OF PUMPING WELL.

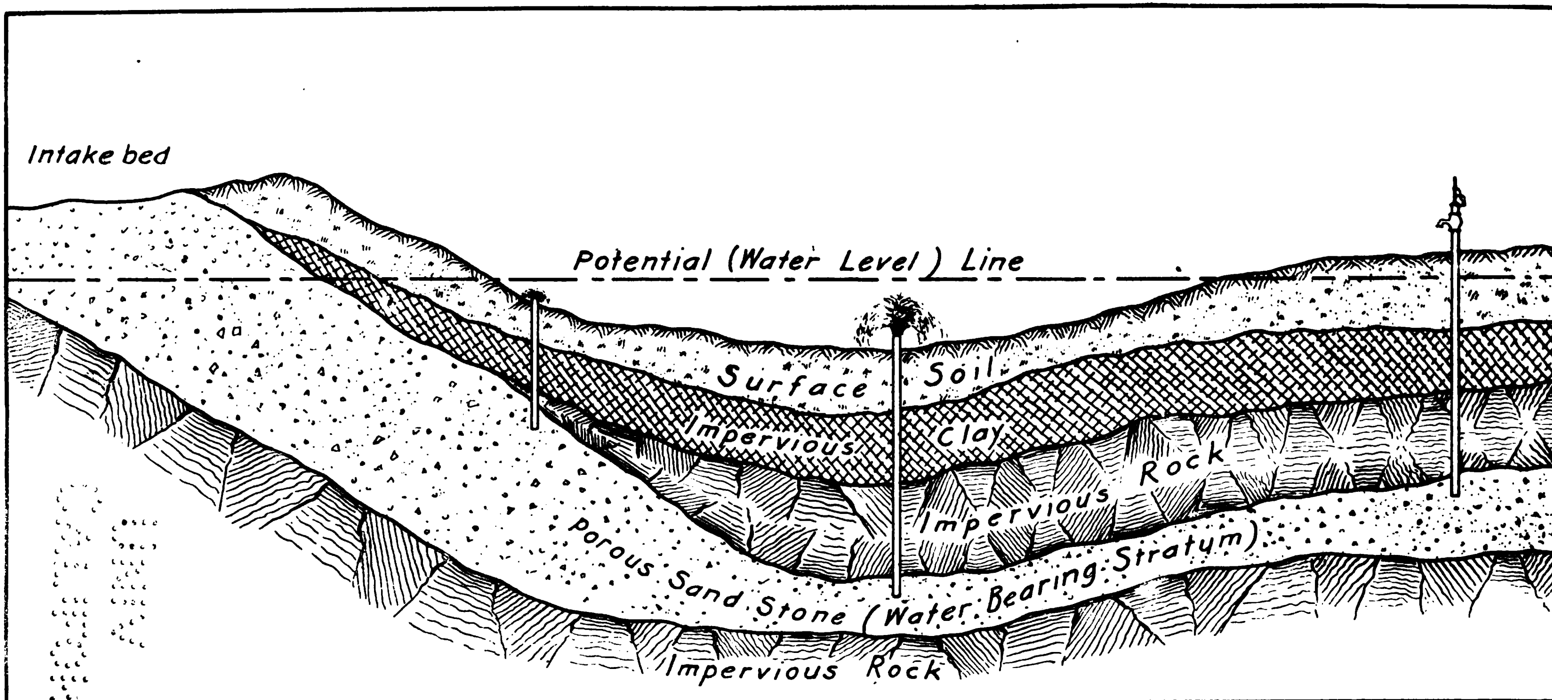


PLATE V. DIAGRAMMATIC SKETCH OF CONDITIONS NECESSARY TO SECURE FLOWING OR PUMPING WELLS.

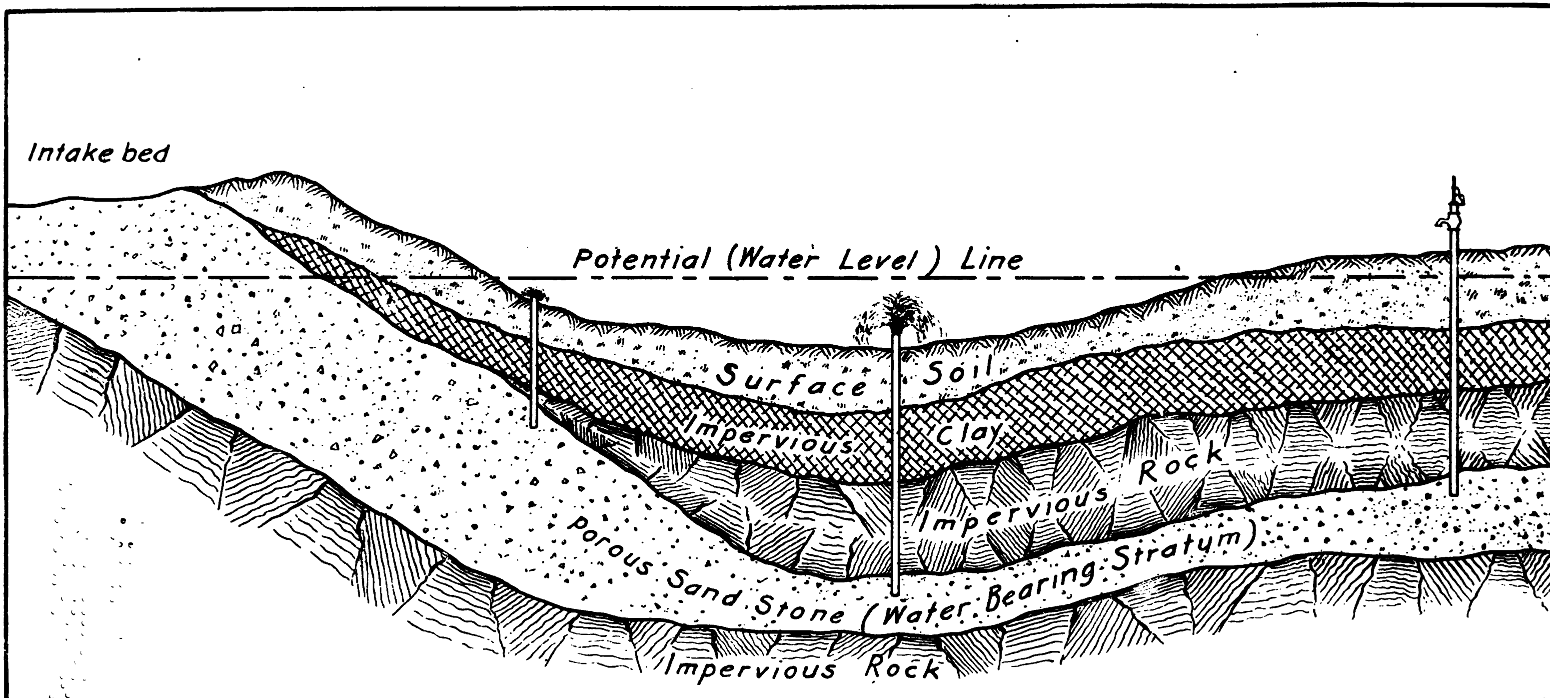


PLATE V. DIAGRAMMATIC SKETCH OF CONDITIONS NECESSARY TO SECURE FLOWING OR PUMPING WELLS.

Fig. 1. Pumping plant, Boac water system, Marinduque, Tayabas Province.

Fig. 2. Hydraulic ram at work on main canal, San Miguel, Tarlac.

PLATE VII.

PLATE VIII. CONCRETE STANDPIPE ON MIRA HILL, TWENTY METERS HIGH. SINGSON WATERWORKS AT VIGAN, ILOCOS SUR.

PLATE IX. GUSHER WELL, SORSOGON. WATER RISING TO A HEIGHT OF OVER 26 METERS.

PLATE X. SPILLWAY OF OSMEÑA WATERWORKS DAM, CEBU, CEBU PROVINCE.

PLATE X. SPILLWAY OF OSMEÑA WATERWORKS DAM, CEBU, CEBU PROVINCE.

PLATE XI. OSMEÑA WATERWORKS, CEBU WATER SUPPLY, CEBU, CEBU PROVINCE.

Fig. 1. Intake and spillway, Sariaya waterworks, Tayabas Province.

Fig. 2. Bamboo waterwheel for hoisting irrigation water.

PLATE XII

Fig. 1. Water wagon used in distributing drinking water to wealthy residents, Iloilo, Iloilo.

Fig. 2. Fountain containing drinking places, faucets, wash places for laundry purposes and bathing facilities back of concrete inclosure.

PLATE XIII.

Fig. 1. Open stone aqueduct, part of the Spanish water-supply system, Lucban, Tayabas Province.

Fig. 2. Open ditches and gutters, part of the Spanish water-supply system, Lucban, Tayabas.

PLATE XIV.

Fig. 1. A stream flowing through Bongabon, Nueva Ecija, a town with malarial index.

Fig. 2. Sibul Springs bathhouse, Bulacan Province.

PLATE XV.

Fig. 1. Spring on seashore at Cebu, Cebu, completely covered at high tide.

Fig. 2. Spring during rainy season.

PLATE XVI.

PLATE XVII. NEAR VIEW OF THE SALINAS SALT SPRING, SALINAS.

Fig. 1. Section of a boiler tube entirely closed with scale, taken from a neglected boiler in the provinces.

Fig. 2. Section of same tube, showing an iron cleaning rod broken off in an attempt to remove the scale.

PLATE XVIII.

Fig. 1. Apparatus used in field assay of water supplies.

Fig. 2. The same, ready for transportation.

PLATE XIX.